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Geology Of The Separation Areas, Hanford Site, South-Central Washington

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Earth Sciences Group
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June 1979

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GEOLOGY OF THE SEPARATIONS AREAS HANFORD SITE, SOUTH-CENTRAL WASHINGTON

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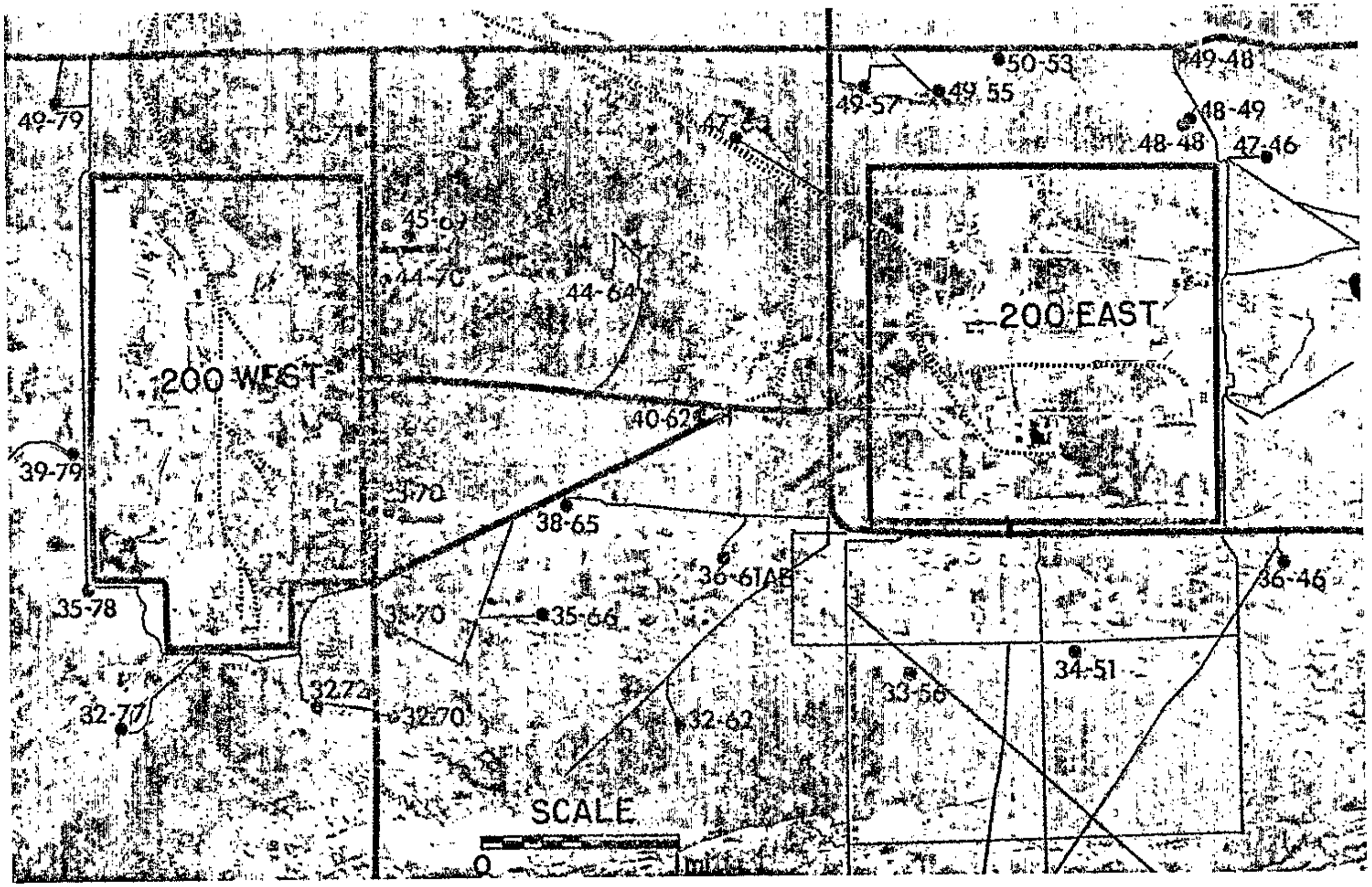

THE SEPARATION AREAS

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SUMMARY

The major geologic units beneath the Separation Areas are, in ascending order; basement rocks of undetermined origin, the Columbia River Basalt Group with intercalated sediments of the Ellensburg Formation, the Ringold Formation, and the glaciofluvial sediments, informally named the Hanford Formation. A loess deposit, referred to as the early "Palouse" soil occurs between the Ringold and Hanford formations in parts of 200 West Area. The surface of the Separation Areas is veneered with loess and sand dunes of varying thickness.

The Columbia River Basalt Group consists of a 5000-foot thick sequence of basalt flows of the Yakima Basalt Subgroup. Interfingered with the upper basalt flows are sedimentary beds of the Ellensburg Formation. The basalt and associated Ellensburg sediments are Miocene in age and the uppermost basalt flow has been dated at 10.5 million years before present by the potassium-argon (K/Ar) method. The Separation Areas are situated on the gently dipping south flank of a basaltic ridge, known as the Umtanum-Gable Mountain Structure.

The Ringold Formation, present throughout most of the Separation Areas, is a Pliocene fluvial sedimentary unit with some lacustrine sediments. This formation can be divided into four major textural units; the silty sandy gravel of the basal Ringold unit, the silty sand to sandy silt of the lower Ringold unit, the silty sandy gravel of the middle Ringold unit, and the silty sand to sandy silt of the upper Ringold unit.

The basal Ringold unit generally lies conformably on the basalt surface and is delineated only in the south and west portion of the study area where it is overlain by the silt and sand of the lower Ringold unit.

After deposition of the basal unit, the silt and sand of the lower unit were deposited in the then forming synclinal depressions. This low energy fluvial-lacustrine deposit is thickest in the southwestern portion of the study area and reaches its maximum thickness south of the Separation Areas in the Cold Creek Syncline. The unit pinches out on the flanks of the Umtanum-Gable Mountain Structure where it was apparently not deposited.

The middle silty sandy gravel unit is the thickest Ringold unit in the study area and is the most important facies of the Ringold Formation

for waste management considerations, because in places it lies above the water table and is involved in vadose zone transport. In general, the upper part of the middle Ringold is not indurated except for isolated cementation from calcium carbonate, while the lower part of the unit is moderately to well indurated.

The upper Ringold unit is present only beneath parts of 200 West Area. This silty sand unit contains several caliche horizons which indicate that the eroded surface of the unit was exposed to subaerial processes of a semiarid to arid environment comparable to the present day climate. The upper Ringold unit apparently was completely stripped by erosion throughout the rest of the study area.

Overlying the upper Ringold unit in 200 West Area is an eolian silt, referred to as the early "Palouse" soil. This silty fine sand to sandy silt was deposited when the wind reworked and deposited Ringold sediments. Relatively high caliche contents are found in much of this unit. Normal fluvial processes as well as Pleistocene catastrophic flooding apparently stripped much of the eolian deposit within the Separation Areas.

The Hanford Formation lies on the eroded surface of the Ringold Formation, the early "Palouse" soil, and locally, the basalt bedrock. Sediments of the Hanford Formation were deposited during Pleistocene catastrophic flooding. The texture of the sediments reflects the changing energy environments during the flooding process. The texture ranges from a silty sandy gravel to a medium-to-very fine sand. Most of this formation within the Separation Areas is in the sand size range with coarser gravel facies in channel fills and on the surface, particularly in the western portion of the study area.

The sediments of the Hanford Formation are the most significant geologic unit in the transport and sorption of radionuclides from surface and near surface waste storage facilities. The Hanford sediments in the Separation Areas effectively isolate and sorb most radiocontaminants (half life greater than one year) discharged to or stored in the ground due to a thick sequence of unsaturated sediments with an adequate sorption capacity. The general horizontal bedding of the Hanford sediments promotes lateral spreading of moisture and retards downward transport of radionuclides.

TABLE OF CONTENTS

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LIST OF FIGURES

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THE GEOLOGY OF THE SEPARATION AREAS

1.0 INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The U.S. Department of Energy's Hanford Site has served as an integrated nuclear facility for plutonium production, nuclear fuel preparation and reprocessing and nuclear waste disposal and management for over 35 years. The site occupies a 570 square mile tract of semiarid land in south-central Washington State (Figure 1.1).

The Separation Areas are located near the center of the Hanford Site on what is commonly referred to as the "200 Area Plateau". This portion of the Hanford Site contains the irradiated uranium fuels processing and plutonium separation facilities and the major radioactive waste storage and disposal facilities. For the purposes of this report the Separation Areas includes 200 East Area, 200 West Area and the adjacent 600 Area. The Separation Areas occupy 24 square miles of the "200 Area Plateau". (Figure 1.1).

Operations in the Separation Areas have resulted in the storage, disposal and accidental release of fission product and transuranic wastes. High-level radioactive wastes have been stored in large underground tanks and in capsules in water basins; low-level* radioactive liquid wastes have been discharged to the sediments via surface and subsurface facilities; and radioactive solid wastes have been buried in the near-surface sediments.

1.2 PURPOSE

The purpose of this study is to integrate and update the available geologic information of the sedimentary units underlying the Separation Areas. This work was sponsored by the Long Term Transuranic Defense Wastes Program.

*For purposes of this report, the term low-level is used to describe both transuranic and fission product wastes that are not high-level waste.

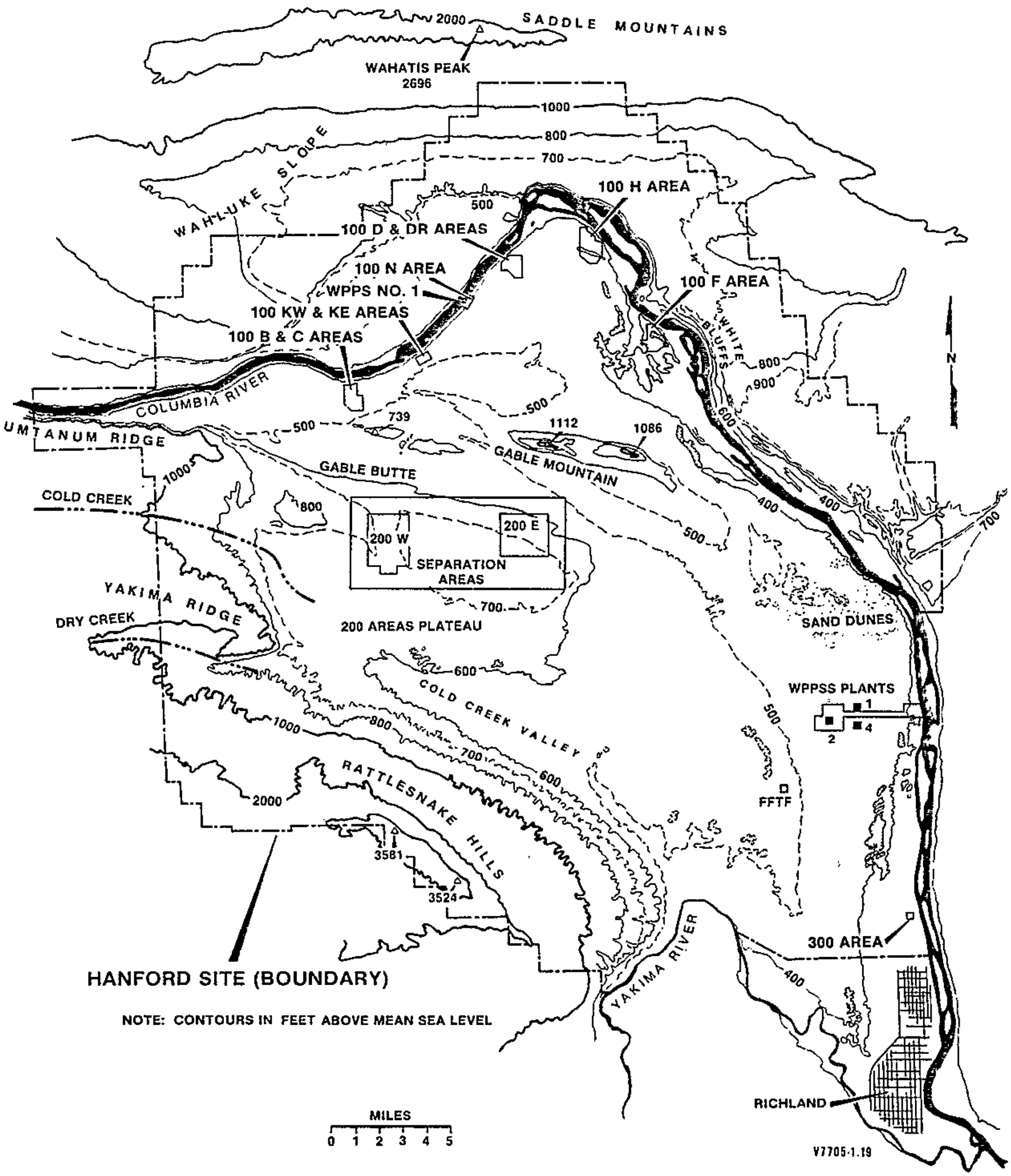

FIGURE 1.1

LOCATION AND TOPOGRAPHY OF THE HANFORD SITE

The geologic information given in this report is intended for use in sorptive modeling and spatial distribution studies of radiocontaminants released to the subsurface environment as well as site selection of future waste management facilities.

The primary sources of information used in this study were geologic logs and sediment samples obtained from well drilling operations. Most wells were emplaced to provide access for various *in situ* instruments and sampling equipment to monitor the ground water and subsurface waste storage and waste disposal facilities. Additional strategically located wells have been emplaced for geologic and/or hydrologic studies (Plate 2, in pocket).

1.3 PREVIOUS WORK

The first geologic investigations of the Pasco Basin area were made about the turn of the century in an effort to evaluate the ground-water resources of the semiarid region of eastern Washington.[1,2,3,4] Additional early studies of the soils,[5] surficial geology[6,7] and hydrology[8] were conducted in the area now known as the Hanford Site.

Operation of the Hanford facilities from 1945 to the present has resulted in discharging large volumes of radioactive liquid waste to the ground beneath the Separation Areas and has prompted extensive investigations into the geologic, hydrologic and sorptive characteristics of the sediments underlying the Hanford Site. Early investigations included work by the U. S. Geological Survey[9,10] and Hanford scientists.[11,12] As more geologic, hydrologic and sorptive characteristics of underlying sediments were known, increased volumes of liquid effluent and increased quantities of radiocontaminants were discharged to the ground.[13,14,15]

After 1955 the volume of radioactive wastes discharged to the near-surface sediments was minimized. By the early 1970's the separation plants were shut down and technical programs in the Separation Areas shifted from reprocessing to nuclear waste management. Much of the work since this transition period has involved the evaluation of various waste disposal sites[16,17,18,19] and waste storage facilities.[20,21,22]

Additional investigations concerning the sediments underlying the Separation Areas have been conducted. This report integrates the results of previous studies concerned with the geology of the Separation Areas.

1.4 WASTE DISPOSAL AND STORAGE FACILITIES

1.4.1 High-Level Radioactive Waste Storage

High-level radioactive waste, produced in the chemical processing of irradiated uranium fuels, has been stored in large underground tanks, built in groups called tank farms. The high-level acidic wastes were neutralized with caustic soda solutions to make these wastes more suitable for storage in metal containers. Neutralization precipitated a major portion of the fission products, resulting in a salt sludge and a supernatant liquid. Between 1952 and 1958 depleted uranium was recovered from these tanks. Since 1952 waste volume reduction has been the primary objective of high-level waste management at Hanford. Volume reduction has been achieved by reducing the amount of high-level waste generated in reprocessing, by special decanting processes, by in-tank evaporation units and by evaporator-crystallizer facilities. In 1968 a waste fractionization plant was placed in operation to remove the high heat emitting fission products, cesium and strontium, from the waste storage tanks.[14]

Initially, 64 "single shell" tanks were constructed for high-level waste storage. An additional 85 underground storage tanks were constructed between 1946 and 1964 to keep pace with continued production output and loss of storage capacity as tanks were removed from service. These "single shell" underground storage tanks varied in size from 55,000 to 1,000,000 gallons and were constructed of reinforced concrete with a single carbon steel liner. In 1966 an improved storage tank with two carbon steel liners, or a "double shell", was conceived.[14] Seven "double shell" tanks have been put into operation. Appendix Figure B.1 shows the locations of the tank farms within the Separation Areas.

1.4.2 Low-Level Liquid Waste Disposal

Ground disposal of liquid radioactive waste from Hanford separations plants began on a limited basis in 1945.[23] Small volumes of selected radioactive waste were initially discharged to the ground by means of subsurface structures, surface ponds and ditches. As more was learned about site geology and waste-sediment interactions, it was concluded that increased volumes of liquid effluent with increased quantities of radionuclides could be safely disposed to the ground.[13,14,15] The rate of waste discharged to the ground reached a peak of 8.34×10^5 curies in 1955.[24] Thereafter, the quantity of radioactive wastes discharged decreased as ground disposal of radionuclides was minimized and separation plants were shut down.

There have been 195 subsurface disposal facilities constructed in the Separation Areas. Several types of facilities have been utilized at Hanford: (1) cribs, which are liquid dispersion systems, used for the disposal of process, condensate and lab wastes; (2) trenches, which are unlined excavations, generally used for short periods for the disposal of high-salt waste or waste containing complexed radionuclides on a specific retention basis; (3) french drains, which are covered or buried gravel-filled encasements with open bottoms, used for the disposal of small-volume and generally low-level waste; and (4) reverse wells, which are buried or covered encased drilled holes with the lower end perforated or open, used for the disposal of process waste.[25] Reverse wells proved unsatisfactory because they plugged easily and introduced waste to the ground at or near the ground water.[12] Therefore, by 1954, all reverse wells had been removed from service.

The large volumes of cooling water and steam condensates from chemical processing facilities and the evaporator-crystallizers are discharged to surface ponds and ditches. Normally the radionuclide concentrations in the effluent is very low. Ponds and ditches are natural or diked surface depressions which allow the liquid effluent to percolate into the underlying sediments. Ditches are unlined excavations used for conveying the cooling water and steam condensate to ponds. Deactivated ponds and ditches have been covered with sediments to prevent resuspension by wind.

1.4.3 Solid Waste Burial

A total of two million curies has been buried in the Separation Areas solid waste burial grounds, which have now decayed to 7.5×10^5

curies. As of December 31, 1977,[26] the following quantities of plutonium, uranium, and thorium have been buried with solid wastes:

	Plutonium (lbs)	Depleted Uranium (lbs)	Enriched Uranium (lbs)	Normal Uranium (lbs)	Thorium (lbs)
Stored Retrievable	237	43	114	154	2,015
Buried, Not Retrievable	785	1,296	392	2,266	788

About 6.7 x 10^6 cubic feet of contaminated solids have been buried in the "200 Area Plateau" since the start of chemical processing operations.[26] These wastes consist of "dry" waste - comprised of soiled clothing, laboratory supplies, tools, etc., packaged in cardboard, wood or metal containers, and industrial waste - primarily items of failed process equipment packaged in plastic shrouds, wood, metal, or concrete boxes.[14]

Burial trenches are unlined excavations partially filled with packaged solid wastes. Trenches are covered with 3 to 10 feet of sediments to reduce surface radiation intensities to less than one millirad per hour.

Transuranic wastes containing more than ten nanocuries per gram have been segregated in specially constructed burial trenches since May 1970. Before that time the transuranic wastes were buried with mixed fission product wastes. Contaminated solid wastes have been buried or stored in 28 sites in the Separation Areas, using 167 acres.

During initial operations at Hanford, wastes that were contaminated or suspected of being contaminated with radioactivity were packaged and buried with no attempt to segregate as to type or level of radioactivity. Segregation was a matter of size. Large equipment, packaged in large wooden boxes, and small miscellaneous materials collected in cardboard cartons, were buried in the same trenches. Methods for estimating the quantity of plutonium contained in wastes were conceived in the late 1950's, and measurement capability was developed in the 1960's.

Prior to 1968, essentially all of the buried wastes in the Separation Areas resulted from operating Separation Areas facilities. Wastes from 300 Area operations and from 100 Area reactors (Figure 1.1) have been buried in the Separation Areas since 1968 and 1973 respectively. Small volumes of solid waste generated at other U. S. Department of Energy sites have been and will continue to be buried in the Separation Areas burial grounds.[14]

1.5 SEDIMENT WASTE REACTIONS

Conceptually, the soils and sediments of the Hanford Site can be divided into three zones based on their desirability for radionuclide waste disposal (storage).[15] The three zones are: (1) the upper vadose (unsaturated) zone above a depth of 20 feet, (2) the vadose zone below 20 feet (lower vadose zone) and (3) the saturated zone. The lower vadose zone is the most desirable waste disposal zone. As long as radionuclides disposed to this intermediate zone do not move, there is a minimal chance of organism contact. Most of the waste and sediment reaction research effort at Hanford has thus been devoted to obtaining the maximum soil retention of radioactive wastes and to the prediction of movement of wastes in this zone. The upper vadose zone is usually least desirable for the disposal of radioactive wastes because of the potential for plant or animal (organism) contact either directly or after possible dissemination by wind, water, and food chains. Thus, only the lowest level wastes are deliberately disposed to this zone. In the saturated zone organism contact will normally not occur with wastes prior to the movement of the ground water to the Columbia River, a distance of over 6 miles requiring several years travel time.[27]

Since early in its history, the objective of Hanford waste disposal practices has been to dispose of low-level radioactively contaminated solutions to the lower vadose zone where sorption is relied on to retain the radioactivity, allowing the decontaminated solution to percolate to ground water. Disposal has been carefully monitored by taking ground-water samples from wells adjacent to disposal structures. When activity in the ground water exceeded 10 percent of concentration guide values for any radionuclide with a half-live greater than 1.0 year, disposal ceased and a new structure was used. Current Hanford disposal guidelines are even more restrictive than the above; essentially no liquid waste is disposed of to the vadoze zone with routine concentrations above concentration guideline limits.

When radioactive waste solutions are percolated through sediments, radionuclides react with, and are retained to a large extent by, the sediments. The sorption of radionuclides can be divided into five categories of reaction: 1) ion exchange, 2) precipitation, 3) coprecipitation and replacement, 4) other sorption reactions, and 5) behavior of neutral and anionic species. The relative importance of the above reactions to the sorption of any given waste solution in low organic matter soil, such as those at Hanford, is a function of both the waste composition and mineralogical composition of the sediments.

1.6 HYDROLOGY

The general hydrologic setting of the Separation Areas is given below. For a more detailed review, the reader is referred to references 10 and 14.

The Hanford Site is drained by the Yakima and Columbia Rivers (Figure 1.1). Short-lived ephemeral streams, Cold Creek and Dry Creek, along the western margins of the Hanford Site may flow for a short period of time after a heavy rainfall or snow melt. Throughout most of the Pasco Basin, however, the landscape is relatively flat and the low mean annual precipitation of 6.25 inches directly infiltrates into the permeable surface fluvial and eolian sediments.[28]

Precipitation that falls on the flat landscape of the "200 Area Plateau" infiltrates directly into the permeable sediments and replenishes deficiencies in the soil moisture of the upper part of the unsaturated zone. Deficiencies result from low annual precipitation and a high evaporation and evapotranspiration rate during the hot summer months. Surface runoff occurs only in man-made ditches that flow to perennial ponds.

The unsaturated (vadose) zone beneath the Separation Areas varies in thickness from about 180 feet to 330 feet. The sediments within this zone are composed predominantly of the Pasco Gravels facies of the Hanford Formation.

The top of the unconfined aquifer is the water table which marks the boundary of the unsaturated and saturated zones. The water table and the stratigraphic formations at the water table are shown in Appendix Figure B.9. The aquifer bottom in the Pasco Basin is either the top of the basalt sequence or the silt and clay of the lower Ringold unit.[14] Beneath the Separation Areas, the bottom of the unconfined aquifer generally coincides with the top of the basalt (Appendix Figure B.2).

The confined aquifer systems at Hanford include the permeable sedimentary interbeds and interflow zones within the basalt sequence and, locally, the sediments in the basal Ringold unit which overlie the basalt sequence.[14,29] Beneath the Separation Areas the top of the confined system is the uppermost flow in the basalt sequence. The thin and discontinuous nature of the lower Ringold in the Separation Areas may permit hydraulic interaction between the middle and basal Ringold units.

1.7 ACKNOWLEDGEMENTS

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2.0 GEOLOGIC SETTING

2.1 REGIONAL GEOLOGIC SETTING

2.1.1 Introduction

Central Washington lies within the Columbia Plateau Physiographic Province, which is generally defined by a thick accumulation of basaltic lava flows that laterally extend from central Washington eastward into Idaho and southward into Oregon (Figure 2.1). In south-central Washington State, deformation of the lava flows has formed a broad structural and topographic basin, the Pasco Basin, in which the Hanford Site lies.

The Pasco Basin is bounded on the north by the Saddle Mountains, on the west by Umtanum Ridge, Yakima Ridge, and the Rattlesnake Hills, on the south by the Rattlesnake Hills and a series of doubly plunging anticlines which merge with the Horse Heaven Hills, and on the east by a broad monocline, locally known as the Jackass Mountain Monocline (Figure 2.2).

The stratigraphy underlying the Pasco Basin is divided into six major units. They are in general ascending order: (1) the basement rocks, (2) the Columbia River Basalt Group, (3) the Ellensburg Formation, (4) the Ringold Formation, (5) the early "Palouse" soil, and (6) the Hanford Formation. Alluvium, colluvium and eolian sediments locally veneer the surface of the Pasco Basin.

2.1.2 Basement Rocks

The basement rocks underlying the basaltic lava flows in the Pasco Basin are of uncertain composition. Pre-basalt rock types can be projected from the margins of the Columbia Plateau, 100 to 150 miles away, and are inferred to exist locally in the central plateau area, perhaps beneath the Pasco Basin. For example, data from the Basalt Explorer Well, northeast of the Pasco Basin, indicate that sandstones and shales comparable to the sedimentary rocks of the Cascade Range may lie beneath the Pasco Basin. Recent magnetotelluric surveys[1] indicate a very deep conductive section, possibly representing these sediments. Beneath these sediments are probably granitic rocks comparable to those

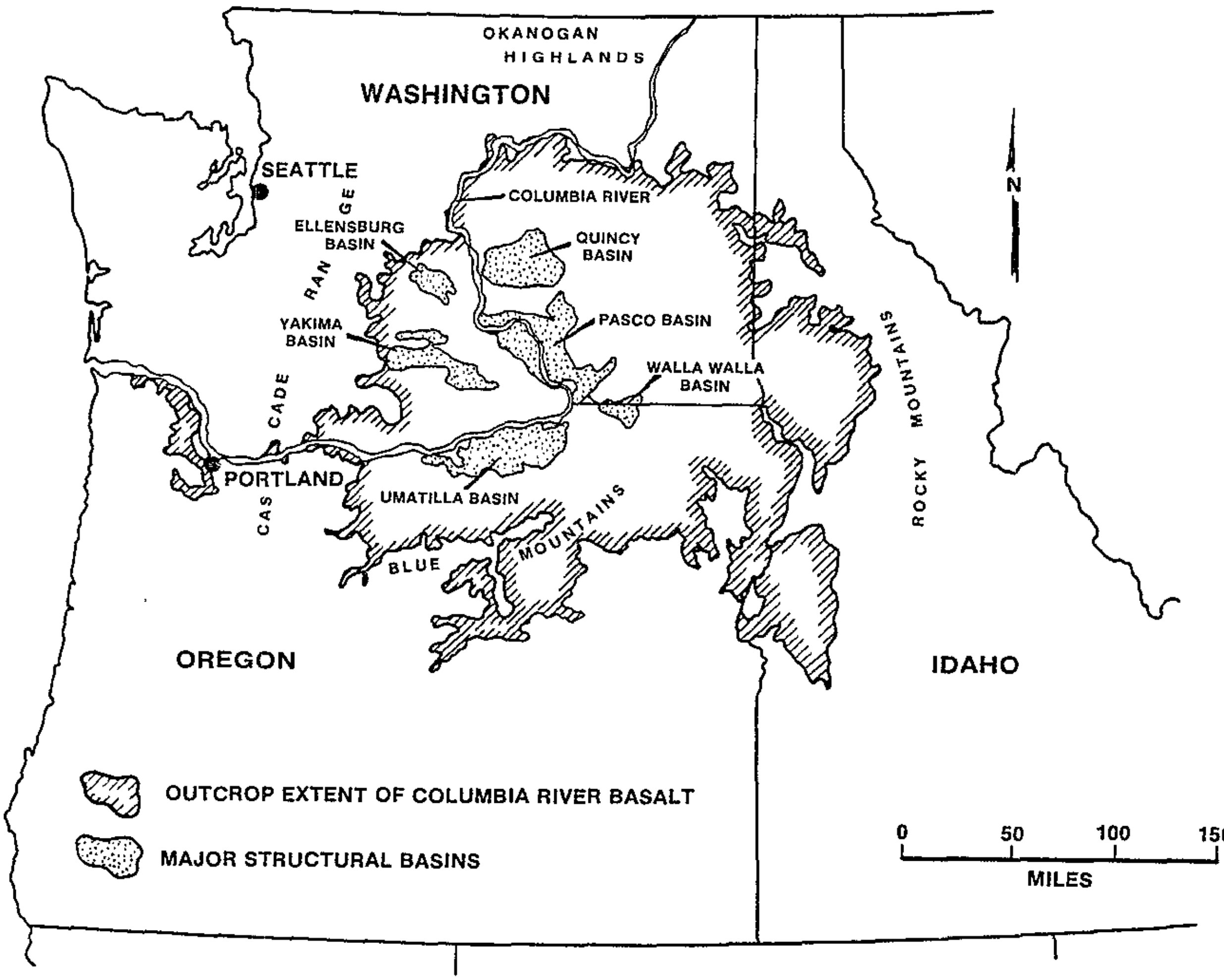

FIGURE 2.1

GEOGRAPHIC EXTENT OF COLUMBIA RIVER BASALT GROUP

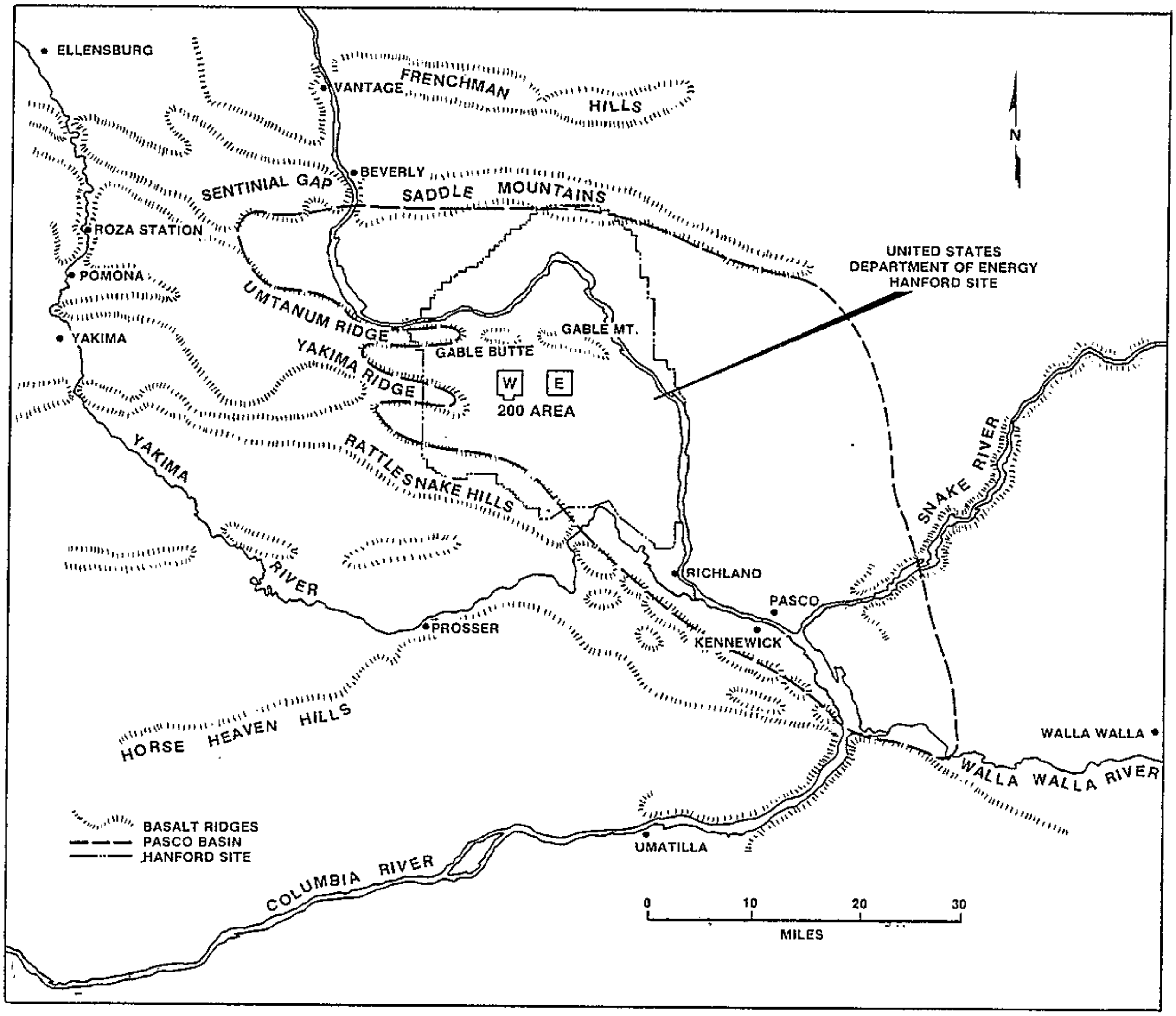

FIGURE 2.2

THE PASCO BASIN AND SURROUNDING AREA

in the Okanogan Highlands, the Snoqualmie Pass area of the Cascade Range, the Moscow Basin, Idaho, the base of the Basalt Explorer Well, and parts of the core of the Blue Mountains, Oregon. There, granitic rocks were intruded into largely Paleozoic and early Mesozoic metavolcanic and metasedimentary rocks, whose equivalents might also occur beneath the Pasco Basin.

2.1.3 Columbia River Basalt Group

The regional geology surrounding the Pasco Basin is dominated by a tholeiitic flood basalt province in the Columbia Plateau and adjacent Blue Mountains of Washington, northern Oregon, and adjacent Idaho (Figure 2.1). The flood basalt province is a layered mass of more than 50,000 cubic miles of basalt covering an area of more than 60,000 square miles. The flood basalts and associated rocks form a plano-convex lens. The upper surface of the lens slopes gently inward except where locally modified by fold systems. Basin deformation and the development of fold systems on the Columbia Plateau started between 16 and 13 million years before present and continued through Columbia River Basalt time.[2]

The basalts emanated from linear fissure systems in the eastern and southern portion of the Plateau.[3,4] Most of the basalt was emplaced during a three-million-year volcanic pulse between 16 and 13 million years before present during the Miocene Epoch.[5] However, sporadic fissure eruptions continued until about six million years before present.[6]

The flood basalts are collectively designated the Columbia River Basalt Group, which have been subdivided into five formations (Figure 2.3).[7,8] The lower two formations are the Imnaha Basalt[9] and the Picture Gorge Basalt.[3] The upper three formations, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt, collectively constitute the Yakima Basalt Subgroup.[8]

In the Pasco Basin, near the center of the area covered by the Columbia Plateau, the basalt sequence is more than 10,000 feet thick[10] and perhaps as much as 19,000 feet thick.[1] In the Basin, a 5,000 foot thick sequence of Columbia River Basalt apparently overlies a series of older basalt of Oligocene to Eocene age.[8] Approximately 100 basalt flows, including both Columbia River Basalt and older lavas

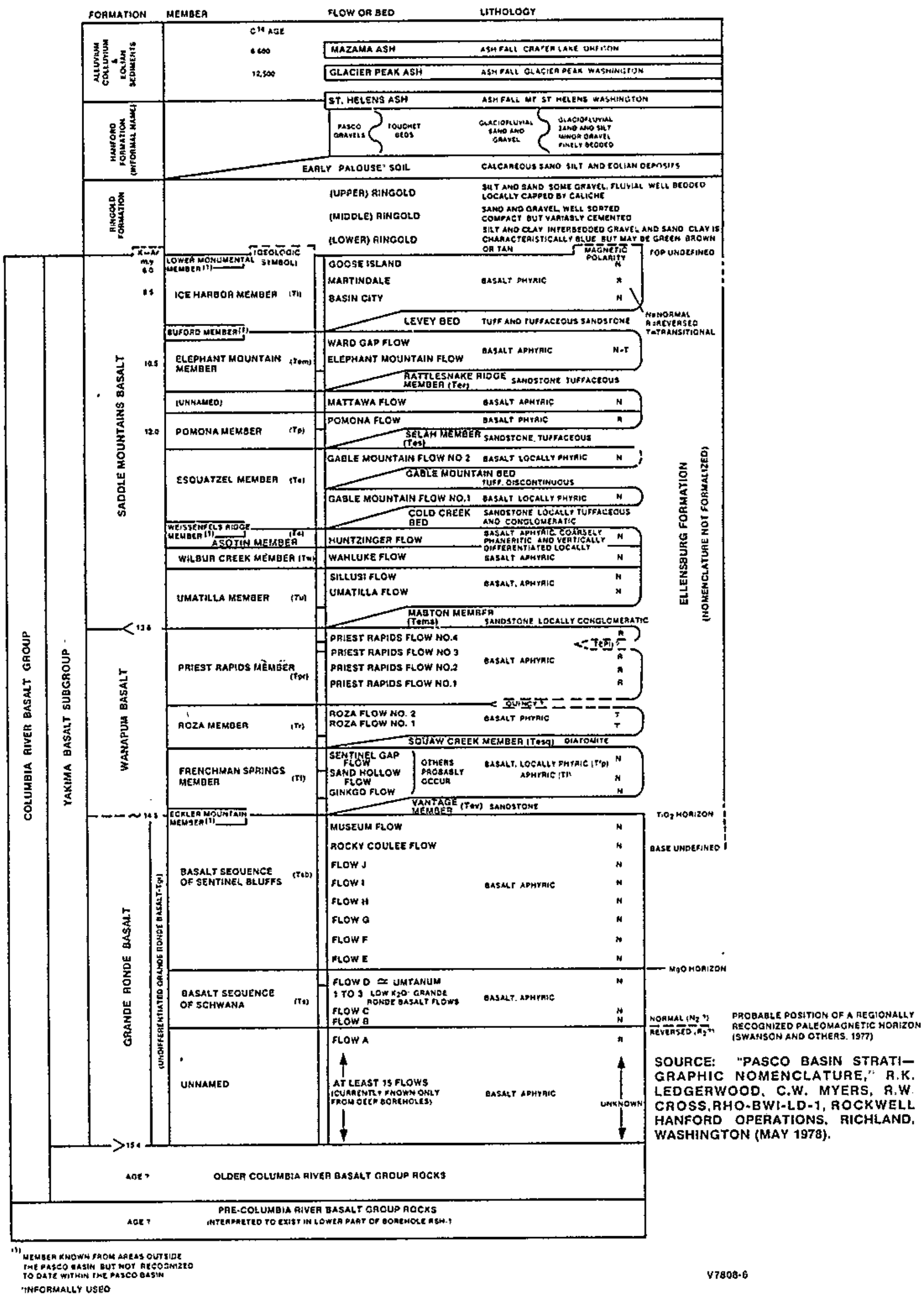

FIGURE 2.3

PASCO BASIN STRATIGRAPHIC NOMENCLATURE

have been identified from geophysical logs obtained from a 10,655 foot deep borehole located along the western margin of the Pasco Basin.[8]

2.1.4 Ellensburg Formation

Within the upper part of the Columbia River Basalt sequence, sediments were transported into the central portion of the Columbia Plateau between basalt eruptions. These sediments which include tuffs and tuffaceous sediments of many kinds, in part now altered to clay, form the Ellensburg Formation.[8] Many basalt flows above the Vantage sandstone horizon are capped locally by stream-deposited sediments. The extent and thickness of the sediments generally increase upward in the section.

About 15 million years ago, ancestral river systems were crossing central Washington, laying down trains of gravel, sand, silt, and clay comparable to today's Columbia River and Snake River sediments. As the plateau subsided, the ancestral Columbia River returned by gravity to the center of the Columbia Plateau leaving sediment trains as a mark of its earlier courses. East of the present course of the Columbia River, sediments are virtually nonexistent between basalt flows. This attests to the ancestral Columbia River course being limited to the western half of the Columbia Plateau.

2.1.5 Ringold Formation

Deformation during the later stages of Columbia River Basalt volcanism resulted in the emergence of the Yakima fold system in the western Plateau. Growth of these folds created a system of structural ridges and basins, which include: the Ellensburg Basin, Quincy Basin, Yakima Basin, Pasco Basin and Umatilla Basin (Figure 2.1). Thick sequences of sediments transported from the surrounding highlands accumulated in these basins.

In the Pasco Basin, the Pliocene[11] Ringold Formation was deposited in response to a flattening of the gradient of the Columbia and Snake River systems, perhaps related to the uplift of the Horse Heaven Hills.[12,13] The Ringold Formation in the Pasco Basin accumulated to a thickness of up to 1,200 feet.

The Ringold Formation can generally be divided into four units on the basis of texture: sand and gravel of the basal Ringold unit; clay, silt and fine sand with lenses of gravel of the lower Ringold unit; occasionally cemented sand and gravel of the middle Ringold unit; and silt and fine sand of the upper Ringold unit (Figures 2.3 and 2.4).[14]

The basal portion of the Ringold Formation is, in general, conformable with the surface of the underlying basalt bedrock. The lower Ringold unit is thickest in the central portion of the Pasco Basin and thins to the basin's margins. The matrix supported conglomerate of the middle Ringold unit overlies the lower unit. The upper Ringold unit is generally confined to the margins of the basin, elsewhere, it either was not deposited, or has been eroded by ancestral river systems and by Pleistocene catastrophic flooding of the basin.

2.1.6 Early "Palouse" Soil

An eolian silt and fine sand (loess) overlie part of the eroded surface of the Ringold Formation in the western part of the Hanford Site (Figures 2.3 and 2.4).[15] Elsewhere the silt was not deposited or was eroded during Pleistocene catastrophic flooding. The silt is considered to be the equivalent to early loesses of the Palouse Hills in eastern Washington and western Idaho. It indicates a climate comparable to that of today, with effective wind transport and deposition of sediment.

2.1.7 Hanford Formation

The Ringold Formation and the basalts and sedimentary interbeds were locally eroded and truncated by multiple floods that occurred as ice-dammed lakes released catastrophic torrents of water and ice when the ice dams were breached during Pleistocene glaciation.[16,17,18] The floods scoured the land surface, leaving a network of buried channels crossing the Pasco Basin.

The glaciofluvial sediments in the Pasco Basin, informally named the Hanford Formation, were deposited on the Columbia River Basalt Group and Ringold Formation (Figures 2.3 and 2.4). These sediments can be divided into the coarser sand and gravel which are referred to as the Pasco Gravels,[19] and the finer sand and silt units called the Touchet Beds.[20]

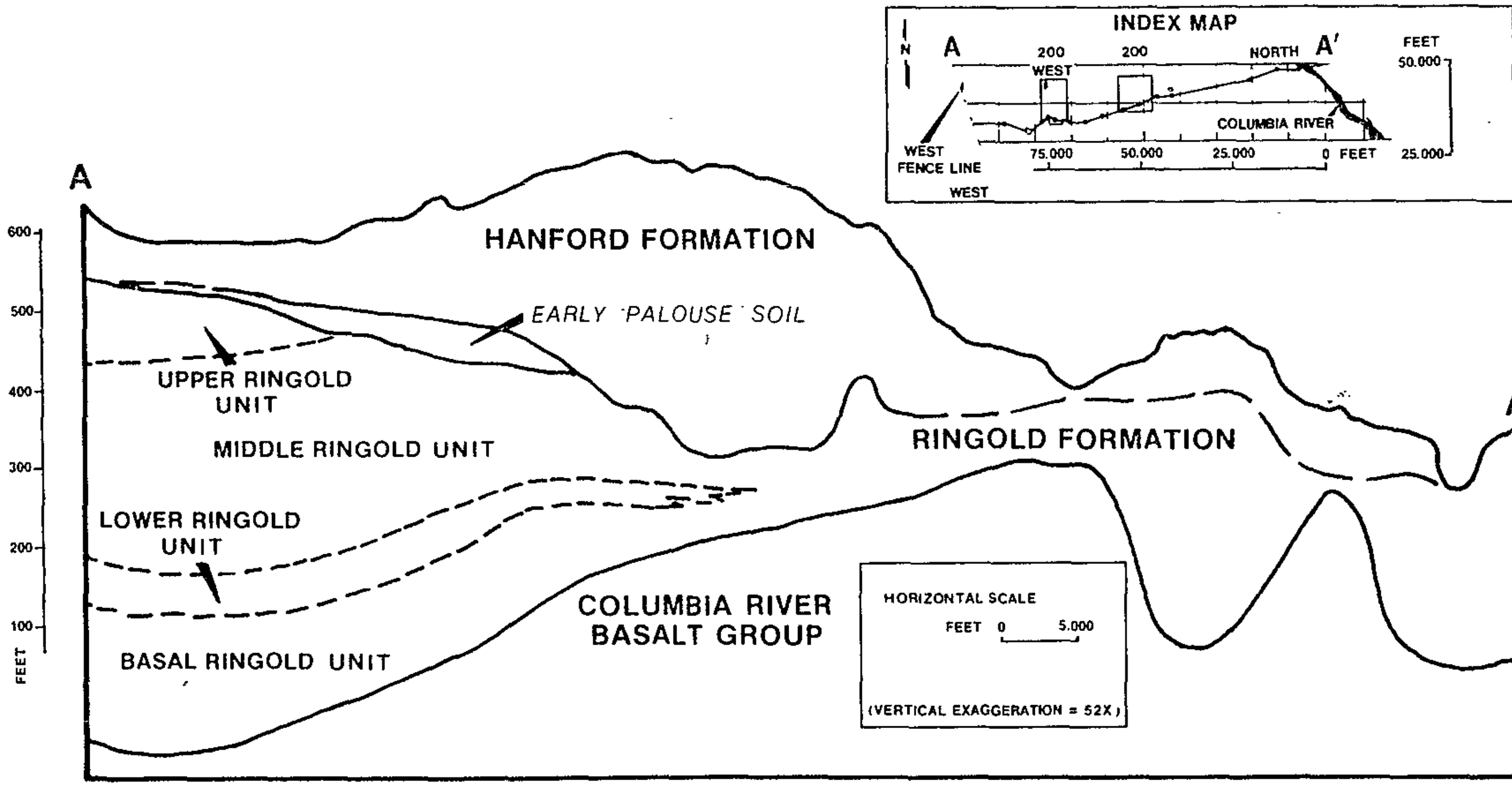

FIGURE 2.4

GENERALIZED GEOLOGIC CROSS SECTION THROUGH THE HANFORD SITE

The Touchet Beds represent low-energy (slackwater) sediments deposited in Glacial Lake Lewis, which formed when flood waters were backed-up behind the Wallula Gap constriction.[20] The Pasco Gravels represent high energy deposition in areas of more rapid water flow. In general, the Touchet Beds are found on the margins of the basin and the Pasco Gravels in and near the center of the basin. The characteristic variability of sediment size and degree of sorting within the "gravel" unit can be attributed to changes in water velocity and water level which occurred during the flooding process. The thickness of the Hanford Formation varies significantly within the basin, with the thickest occurrence in the region of buried channels.

2.1.8 Eolian Deposits

Loess and sand dunes mantle the surface of the Pasco Basin.[21] These deposits are primarily reworked sediments of the Hanford Formation from surrounding areas. The thickness of the wind-blown sediments varies considerably, ranging from zero to more than 30 feet in some dunes.

2.2 SITE GEOLOGIC SETTING

The Separation Areas lie in the Pasco Basin near the eastern limit of the Yakima fold system. The site is situated on the south flank of the Umtanum-Gable Mountain Structure.[22] The basalt bedrock dips to the southwest and sediments increase in thickness to the south where they reach a maximum in the Cold Creek Syncline.[23] The deepest part of the Pasco Basin is a few miles to the southeast of the Separation Areas where the basalt surface is about 150 feet below sea level.[24,25]

All four units of the Ringold Formation are present in the subsurface within the study area and show varying degrees of erosion and incision by both normal fluvial processes and catastrophic Pleistocene floods. The Separation Areas lie on a broad bar formed when Pleistocene flood waters spread out beyond the Umtanum-Gable Mountain Structure depositing the sand and gravel of the Hanford Formation. The flood bar, roughly defined by the 700 foot contour line, is commonly referred to as the "200 Area Plateau."

The land surface has been only slightly modified since the deposition of the Hanford Formation. Eolian erosion and deposition have resulted in minor deflation and deposition of sand and silt veneers up to 25 feet thick.

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3.0 STRATIGRAPHY

3.1 INTRODUCTION

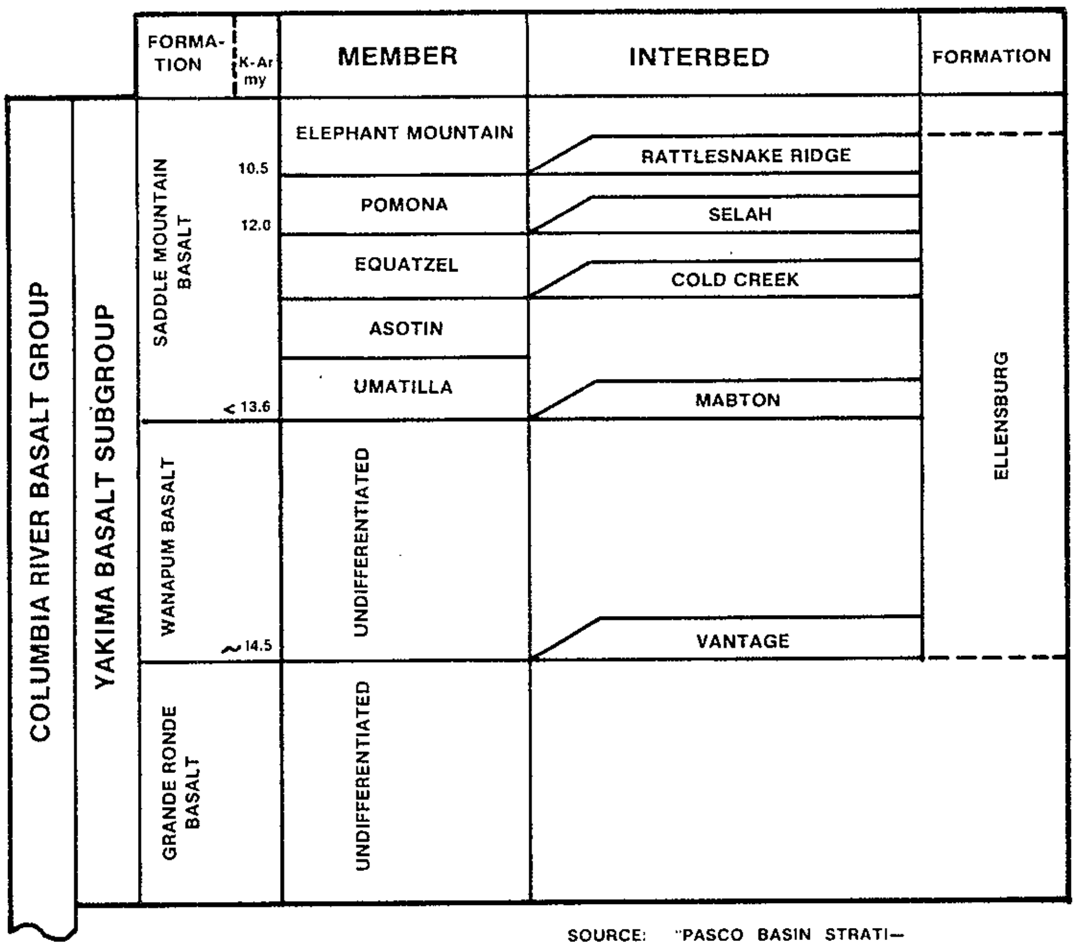
The stratigraphy beneath the Separation Areas consists of three basalt formations. In ascending order these are, the Grande Ronde, Wanapum, and Saddle Mountains formations, collectively termed the Yakima Basalt Subgroup.[1,2,3] The Ringold Formation overlies the Saddle Mountains Basalt and is generally conformable to the basalt surface.[4] Overlying the Ringold are the glaciofluvial sediments,[5] informally named the Hanford Formation. Two important nonformational units, the early "Palouse" soil[6] and the surface loess deposits[7] are also found in the Separation Areas. The stratigraphic cross sections are given in Appendix Figures A.2 through A.8. The lithofacies geologic cross sections are given in Plates 3 through 12 in the pocket.

3.2 COLUMBIA RIVER BASALT GROUP

The Columbia River Basalt Group underlying the Separation Areas consists of a 5000-foot thick sequence of basalt flows which constitute the Yakima Basalt Subgroup and includes the Grande Ronde Basalt, the Wanapum Basalt and the Saddle Mountains Basalt (Figure 3.1).[2] For purposes of this report the Saddle Mountains Basalt has been subdivided into members, whereas, the Wanapum and Grande Ronde basalts remain undifferentiated.

The Saddle Mountains Basalt within the study area consists of four members which are, from oldest to youngest: the Umatilla, Esquatzel, Pomona and Elephant Mountain.[3] A fifth member, the Asotin, is present east of the Separation Areas. Interfingered with many of the Saddle Mountains Basalt flows are sedimentary beds. The major interbedded sediments are the Mabton, Cold Creek, Selah and Rattlesnake Ridge which form part of the Ellensburg Formation.[3] The stratigraphic relationships of the Yakima Basalt Subgroup and the upper beds of the Ellensburg Formation have been determined from corehole data and are shown in Figure 3.2.

The topmost and youngest basalt member in the north-central portion of the Pasco Basin and Separation Areas is the Elephant Mountain Member.[8] The member consists of one flow, up to 100 feet thick that



SOURCE: "PASCO BASIN STRATIGRAPHIC NOMENCLATURE," R.K. LEDGERWOOD, C.W. MYERS, R.W CROSS, RHO-BWI-LD-1, ROCKWELL HANFORD OPERATIONS, RICHLAND, WASHINGTON (MAY 1978).

FIGURE 3.1

STRATIGRAPHIC NOMENCLATURE OF THE BASALT AND INTERBEDS OF THE SEPARATION AREAS

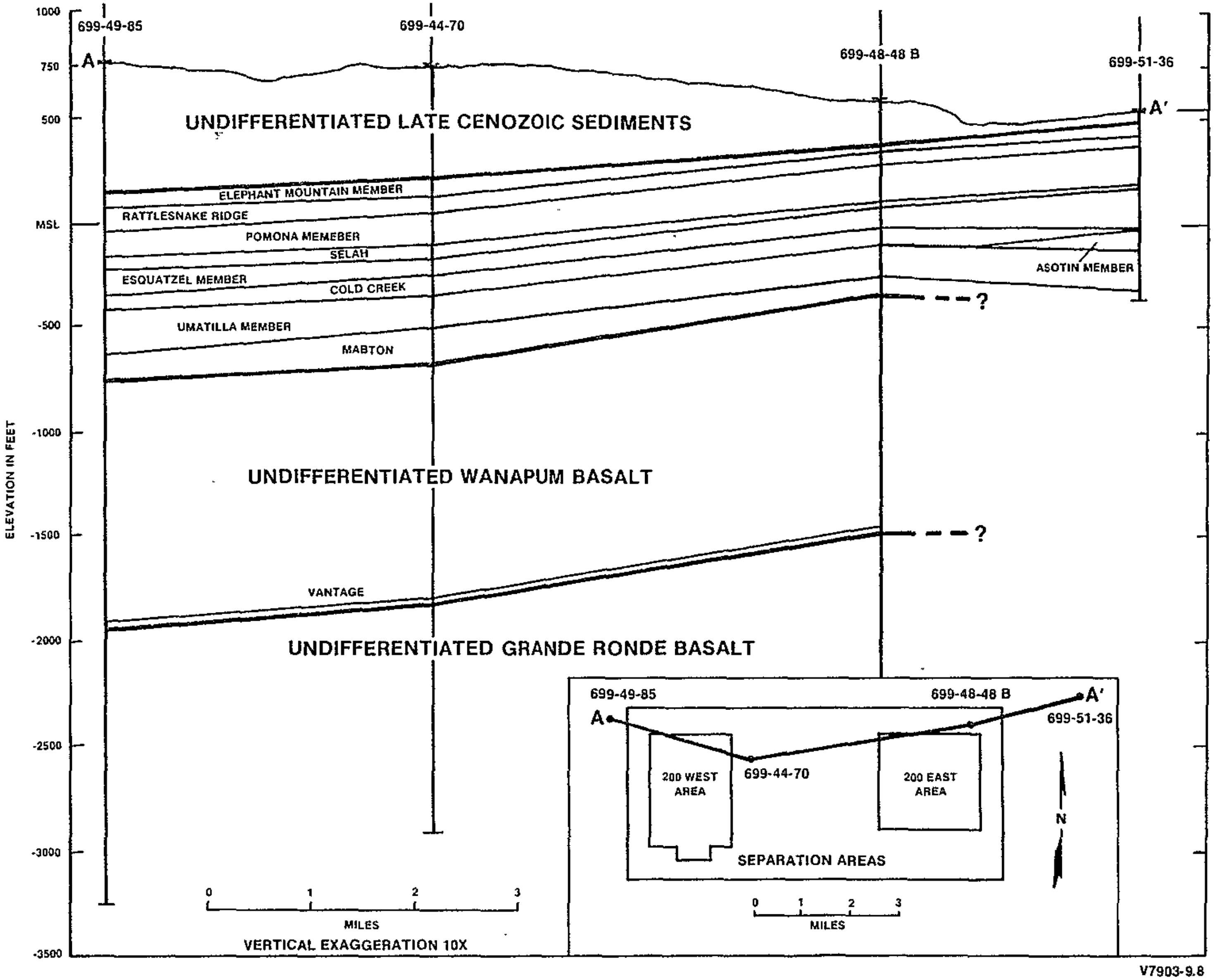


FIGURE 3.2

GENERALIZED EAST-WEST CROSS SECTION OF
THE BASALT SEQUENCE BENEATH THE SEPARATION AREAS

has been radiometrically dated (K/Ar) at about 10.5 million years before present.(1) The Elephant Mountain flow crops out on Gable Mountain and Gable Butte(8) to the north of the study area and dips gently to the southwest under the Separation Areas into the Cold Creek Syncline.(9,10) The elevation of the surface of the Elephant Mountain flow is greater than 400 feet above mean sea level in the northeast corner of the study area and about mean sea level in the southwest corner (Appendix Figure B.2).

The basalt high in the northeast corner of Figure B.2 is one of the parasitic folds within the closure of the major, easterly trending, Umtanum-Gable Mountain Structure.(8) These parasitic folds have a general northwesterly trend. The parasitic fold in the Separation Areas has been breached by an ancient stream and by catastrophic flooding that incised a 140-foot channel into the major fold (Appendix Figure B.2).

3.3 RINGOLD FORMATION

The Ringold Formation directly overlies the basalt sequence and is present throughout the Separation Areas except in the northeast corner of the study area.(4) There the Ringold sediments have apparently been completely removed by erosion. All four textural units of the Ringold Formation: the silty sandy gravel of the basal Ringold unit, silty sand to sandy silt of the lower Ringold unit, silty sandy gravel of the middle Ringold unit, and silty sand to sandy silt of the upper Ringold unit are present beneath the Separation Areas (Appendix Figures A.2 through A.8).

The thickness of the Ringold Formation varies from zero in the northeast portion of the study area to a maximum thickness of about 540 feet in the southeastern portion (Appendix Figure B.3). The Ringold Formation generally thickens to the south into the Cold Creek Syncline. This thickening to the south primarily reflects the slope of the northern flank of the Cold Creek Syncline.(9) Also, in the northern and northeastern portions of the Separation Areas, main side stream currents of late Pleistocene flooding have deeply eroded into the Ringold Formation (Appendix Figures A.2 and A.3, Plates 4 and 6).

3.3.1 Basal Ringold Unit

The basal Ringold unit, a silty sandy gravel, overlies the basalt sequence and associated interbedded sediments. Beneath the southern portion of the Separation Areas the basal Ringold is overlain by the finer-grained lower Ringold unit. Here the basal Ringold is well defined (Appendix Figures A.2 through A.6). In the northern portion of the Separation Areas the lower Ringold unit is not present and the basal Ringold can not be readily distinguished from the middle Ringold unit. The basal and middle Ringold units are texturally, as well as mineralogically, similar (Appendix E). Therefore, lateral continuity of this unit throughout the Separation Areas has not been delineated.

From the southern portion of the Separation Areas into the Cold Creek Syncline the basal Ringold is between 50 and 125 feet thick. This unit is generally conformable to the Elephant Mountain flow and, like the basalt surface, (Appendix Figure B.2) has a gentle southwesterly dip. The elevation of the surface of the basal Ringold unit ranges from 350 to 140 feet above mean sea level.

The basal Ringold unit is composed predominantly of gravel that is supported by a coarse-to-fine sand matrix. Stringers of coarse-to-fine sand and silt are common throughout the unit. At the base of the unit the sand becomes more basaltic reflecting the proximity to the underlying basalt. Along the southern margin of the Separation Areas stringers of sand and silt are more abundant near the contact with the lower Ringold unit than in the central portion of the basal Ringold unit. Further to the north the upper and lower contacts of the basal Ringold unit are sharp. Examples of texture and $CaCO_3$ content for the predominant gravel facies of the basal Ringold unit are given in Table 3.1. This unit is not known to crop out in the Pasco Basin, therefore, interpretation of sedimentary structures within the unit is based on core samples. The predominantly gravel unit is interpreted to be massively bedded.

The pebble and cobble fraction of the basal Ringold is composed of basalt, quartzite, metamorphics, granitics and other lithologies from outside the Pasco Basin. The basalt content of selected samples from the basal Ringold is shown in Appendix Table E.3. The sand fraction is made up of quartz and feldspar (plagioclase and orthoclase) with variable

TABLE 3.1

TEXTURE AND CALCIUM CARBONATE EXAMPLES
BASAL RINGOLD UNIT

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand					% Silt & Clay	$\%CaCO_3$
		Very Coarse	Coarse	Medium	Fine	Very Fine		
299-W22-24 470' Sandy Very Coarse To Fine Pebble	56.6	27.9	9.3	3.5	1.3	0.7	0.7	0.5
699-36-61B 535' Silty Sandy Medium To Fine Pebble	31.6	15.9	13.5	15.2	9.5	4.9	9.3	0.2

amounts of other minor constituents (Appendix Table E.2). The silt and clay sized fractions contain quartz, feldspar (plagioclase and orthoclase), chlorite, mica and smectite. (Appendix Table E.1). Chlorite, smectite and mica have relatively high cation exchange capacities but make up a very small percentage of total sample.

These sediments were deposited by slope wash on the basalt surface as well as drainage through the Basin as evidenced by the presence of lithologies from outside the Pasco Basin. The relatively consistent thickness, with negligible thickening in the Cold Creek Syncline to the south[9], suggests that these gravels were deposited before the major deformation of the Cold Creek Syncline.

It was suggested by Brown and Brown[11] that these basal Ringold sediments may be equivalent to interbeds beneath younger basalt flows outside the north-central portion of the Pasco Basin. More stratigraphic information is necessary to confirm or negate this hypothesis.

3.3.2 Lower Ringold Unit

The lower Ringold unit occurs only in the western and southern part of the Separation Areas (Appendix Figures A.2 - A.6). It ranges in thickness from about 25 feet in the northern part of the 200 West Area to a maximum of 100 feet in the southwestern part of 200 West Area. The surface of this unit dips to the southwest with the elevation of the surface ranging from 375 to 200 feet. South of the study area in the

Cold Creek Syncline, the lower Ringold reaches a thickness of greater than 350 feet. The contact with the overlying middle Ringold unit is sharp.

The texture of this unit ranges from a silty coarse-to-medium sand to a sandy silt, with a general fining of the sediments from north to south (Plates 3,5,6,7,8,9 & 10). Examples of textural and $CaCO_3$ values are given in Table 3.2. Stringers of coarse-to-fine pebbles up to one foot thick are common. Also, fine pebbles are scattered throughout beds within the units, but this is not typical. There are no known surface exposures of the lower Ringold, therefore, it is known only from core and grab samples collected during drilling operations. Where observed in core, the unit is finely bedded to massive.

TABLE 3.2

TEXTURE AND CALCIUM CARBONATE EXAMPLES
LOWER RINGOLD UNIT

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand					% Silt & Clay	$\%CaCO_3$
		Very Coarse	Coarse	Medium	Fine	Very Fine		
699.-35-66 425' Silty Medium to very fine sand	3.5	2.2	9.4	19.6	14.8	14.4	36.2	0
299-W22-27 500' Silty Fine to very fine sand	.1	.1	12.7	17.9	25.3	21.4	22.4	.9
299-W19-8 440' Silty coarse to medium sand	.5	1.9	27.3	24.8	15.5	9.3	20.6	.3
299-E13-8 453' Sandy Silt	.0	.0	.0	.0	16.1	24.9	59.0	.0

The sediments are composed primarily of quartz and feldspar (plagioclase and orthoclase) with basalt occurring only in coarser pebble lenses (Appendix Table E.2 and E.3). The silt and clay sized fractions are composed of mica, smectite, chlorite and quartz (Appendix Table E.1). The properties of this facies in the Separation Areas suggest deposition in a low energy flood plain or lacustrine environment. The thick accumulation in structural lows suggests that deposition took place during and/or after major deformation of the Basin.

The thinning and disappearance of the lower Ringold in the northeastern portion of the Separation Areas can be interpreted as a lack of deposition of fine grained sediments on the topographically higher flank of the Cold Creek Syncline, as well as subsequent erosion of areas of thinner deposition.

3.3.3 Middle Ringold Unit

The silty sandy gravel of the middle Ringold unit occurs throughout the Separation Areas except in the deep channel in the northeast corner. This facies is the major constituent of the Ringold Formation in the Separation Areas. It overlies the silt and sand of the lower Ringold and, where this unit is not present, the middle Ringold has not been separated from the basal unit (Appendix A). Separation of these two facies, if possible, requires more detailed study of clast composition.

The elevation of the surface of the middle Ringold facies ranges from 400 to 600 feet above mean sea level. The morphology of the surface of the middle Ringold is shown in Appendix Figure B.4. The thickness of the middle Ringold unit is up to 350 feet in the southern part of the study area, with a general thinning to the north and east. Erosion by normal fluvial processes and/or Pleistocene floods has removed part of the middle Ringold in much of the study area. Where the middle Ringold is reworked by Pleistocene floods, it is often difficult to separate from the Hanford Formation.

The unit consists of well rounded pebbles and small cobbles with interstitial spaces filled with coarse-to-fine sand and silt (Figure 3.3). The amount of cementation is variable but generally is greatest in the lower part of the unit. The lower part of the conglomerate is moderately to well indurated with calcium carbonate and/or silica. Zones of poorly indurated conglomerate and sand occur within this lower cemented section. Silt and sand lenses are present within the conglomerate and are up to 15 feet thick with many minor stringers less than 1 inch thick. The upper part of the conglomerate is generally noncemented except for local zones of $CaCO_3$. Examples of textural and $CaCO_3$ values for the middle Ringold unit are given in Table 3.3.

TABLE 3.3

TEXTURE AND CALCIUM CARBONATE EXAMPLES
MIDDLE RINGOLD UNIT

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand Very Coarse	Coarse	Medium	Fine	Very Fine	% Silt & Clay	$\%CaCO_3$
299-E17-8 310' Silty sandy medium to fine pebble	46.1	10.5	8.2	6.9	6.7	6.4	15.2	.3
299-W11-3 150' Sandy very coarse to fine pebble	49.4	10.1	17.6	9.7	4.8	3.5	5.0	1.8
299-W22-25 295' Silty medium sand (Sand Lense)	4.5	7.8	13.1	41.0	16.4	7.2	10.0	.4

The composition of the nonbasaltic gravel fraction is predominantly quartzite with metamorphic, granitic, and volcanic porphyry rocks derived from outside the Columbia Plateau. The basalt gravel fraction is composed of Columbia River Basalt and is usually highly altered due to hydration and physical disintegration. The total percent basalt is highly variable (Appendix Figure E.3) and appears to be related to proximity of basalt highs during middle Ringold deposition. The sand fraction is predominantly quartz and feldspar (orthoclase and plagioclase) with the silt and clay size fractions composed of quartz, feldspar and smectite (Appendix Figures E.1 and E.2).

The Ringold conglomerate is not exposed in the Separation Areas and can only be observed in core and grab samples from wells. It is, however, exposed at the White Bluffs 6 miles southeast of the Separation Areas. The conglomerate unit in cores from 10 wells within the study area is not apparently bedded. The conglomerate at the White Bluffs exposure has a massive appearance with minor imbrication of clasts (Figures 3.4). Cross-bedding is common in the sand and silt lenses in both the cores and White Bluffs exposure (Figure 3.5).

Much of the well-indurated conglomerate facies is made up of a relatively well sorted coarse-to-medium sand matrix with very coarse pebbles and small cobbles. It is typically matrix supported with individual pebbles and cobbles completely separated by sand (Figure 3.6).

1 Inch

FIGURE 3.3

CORE OF MIDDLE RINGOLD UNIT WELL
299-W11-26 DEPTH 246 FEET

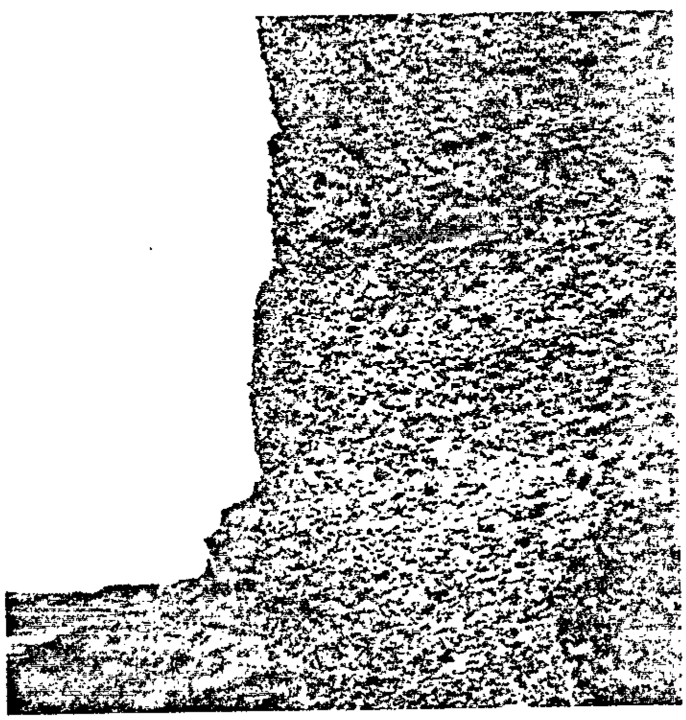


FIGURE 3.4

MIDDLE RINGOLD UNIT EXPOSED
ALONG THE WHITE BLUFFS

FIGURE 3.5

CROSS BEDDED SAND IN MIDDLE
RINGOLD UNIT AT WHITE BLUFFS

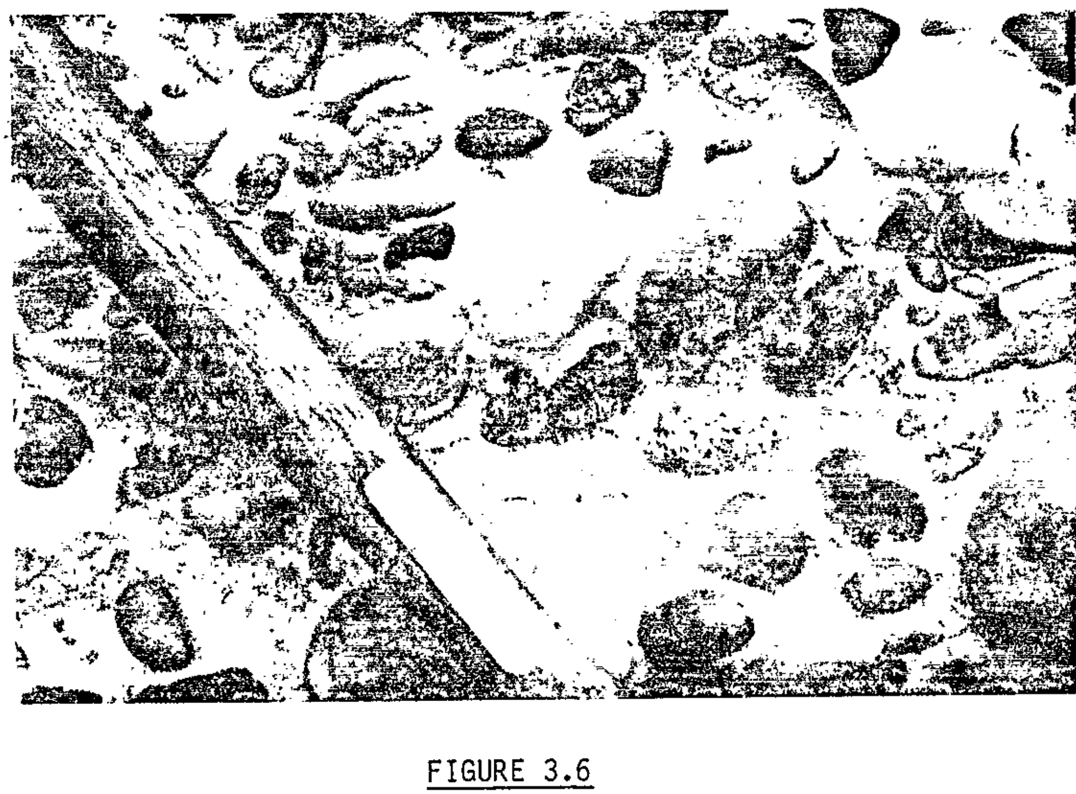


FIGURE 3.6

MATRIX SUPPORTED MIDDLE RINGOLD
UNIT AT THE WHITE BLUFFS

Open worked gravels which contain little or no sand fraction occur in lenses at the White Bluffs exposure and are occasionally found in core wells.

The middle Ringold was deposited in a high energy fluvial environment. The particle roundness and the exotic lithologies both attest to transport over considerable distance. This ancient drainage system deposited coarse detritus, typical of a highly particle-charged stream, across the Pasco Basin. The change from the fine-grained sediments of the lower Ringold to the coarse conglomerate facies is usually sharp and indicates an abrupt increase in stream gradient and/or a new source of coarse detritus. More regional stratigraphic studies are necessary to determine the paleodrainage of the region during middle Ringold time and the source area of the sediments.

3.3.4 Upper Ringold

The sand, silt and clay of the upper Ringold is delineated only in the western part of the Separation Areas (Appendix Figures A.2 through A.6).[4,12,13,14,15,16,17] It occurs at an elevation of 500 to 600 feet, decreasing in elevation from north to south[4,18] and has a maximum thickness of about 50 feet.

The unit is composed of well-sorted sand and silt with minor lenses of fine pebbles (Table 3.4). Quartz and feldspar (orthoclase and plagioclase) make up more than 50 percent of the sediments with a relatively high percentage of calcite in caliche horizons (Appendix Tables E.2 and E.3). Quartz, feldspar and mica are present in the silt fraction and quartz, smectite and mica are common in the clay sized fraction (Appendix Table E.1). A caliche horizon often caps the upper Ringold and other caliche horizons have been identified throughout the unit.[15,16,17,19]

This unit is not exposed in the Separation Areas, but core and grab samples reveal sand layers alternated with silt and clay. The textural boundaries are usually sharp.

More than 400 feet of upper Ringold section is exposed in the White Bluffs section, 6 miles east of the study area. Here the silt and clay layers are typically horizontally bedded with fine laminations and lack current sedimentary structures. Sand units are both horizontal and cross-bedded with ripple marks commonly present (Figures 3.7 and 3.8).

TABLE 3.4

TEXTURE AND CALCIUM CARBONATE EXAMPLES
UPPER RINGOLD UNIT

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand Very Coarse	Coarse	Medium	Fine	Very Fine	% Silt & Clay	%$CaCO_3$
299-W11-1 150' Silty fine to very fine sand	1.5	1.7	3.5	12.9	26.6	29.8	24.0	4.0
299-W10-4 110' Calcareous silty medium to fine sand	4.1	5.7	9.4	21.6	25.1	14.7	19.4	22.0
299-W22-23 225' Sandy silt	.8	1.1	2.7	5.2	5.9	13.0	71.2	3.2
299-W22-28 225' Silty Medium to very fine sand	.3	.2	.5	11.1	46.3	18.9	22.8	.9
299-W22-28 145' Calcareous pebbly coarse to very sand	14.0	6.5	18.2	21.1	11.2	10.7	18.2	12.5
299-W18-3 165' Slightly silty medium to fine sand	.0	.1	3.1	34.4	32.4	11.9	18.1	.0
299-W18-7 145' Slightly calcareous silty sandy fine to very fine pebble	44.2	18.3	8.6	6.9	5.0	4.2	12.9	6.7

The sediments of the upper Ringold were deposited in a lower energy fluvial system with local lacustrine environments. The caliche horizons in the upper Ringold indicate a semiarid climate similar to that of today. After deposition of the upper Ringold, the top of the unit was subjected to subaerial erosion. Much of the upper Ringold was apparently stripped from the Separation Areas.[20-31] A well developed caliche horizon in most wells penetrating the upper Ringold unit indicates that the surface of the upper Ringold unit in the Separation Areas was exposed to subaerial processes for a relatively long period of time.

3.4 EARLY "PALOUSE" SOIL

The surface of the Ringold was altered by wind which reworked and redeposited the fine-grained sand and silt. An eolian deposit is present in the western part of the Separation Areas where it overlies upper Ringold sediments. This buried loess, termed early "Palouse" soil,[32,33] is up to 50 feet thick within the study area. The surface of the eolian silt occurs at an elevation of 500 to 600 feet above mean sea level (Appendix Figure B.5).

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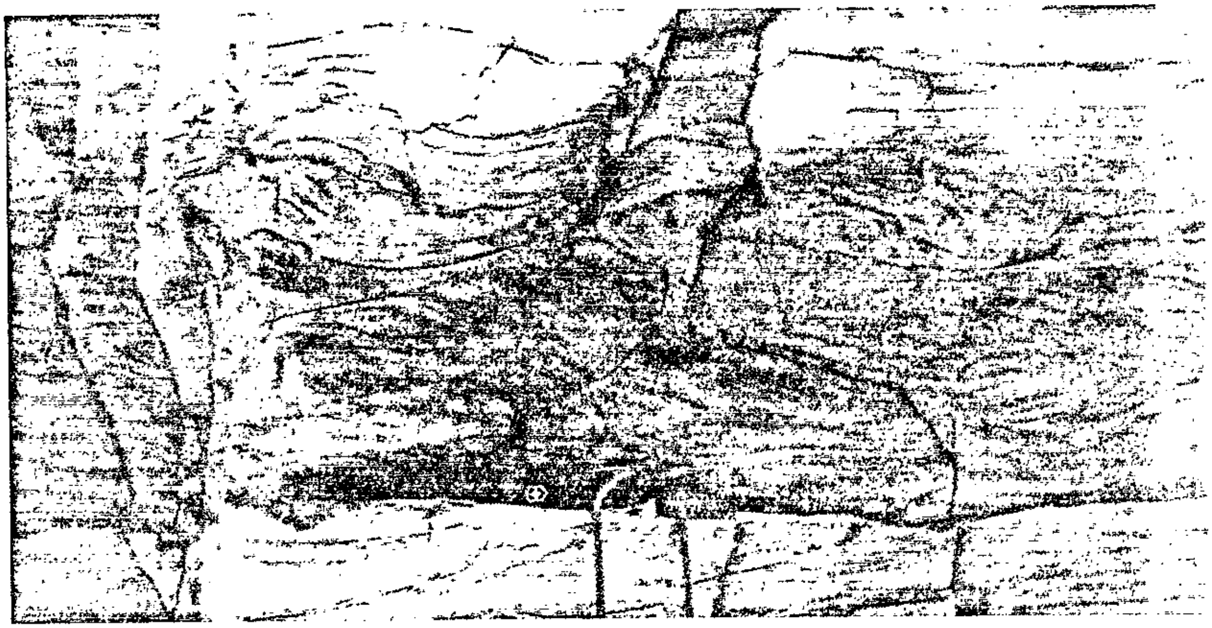

FIGURE 3.7

UPPER RINGOLD UNIT AT THE
WHITE BLUFFS

FIGURE 3.8

RIPPLE MARKS IN THE UPPER
RINGOLD UNIT AT THE WHITE BLUFFS

The sediments are typically fine grained, consisting predominantly of very fine sand and silt (Table 3.5). The major mineral constituents are quartz and feldspar (orthoclase and plagioclase), with quartz sand grains commonly frosted (Appendix Table E.2). The less than 2μ size fraction contains smectite, mica and chlorite (Appendix Table E.1), resulting in a relatively high cation exchange capacity.

TABLE 3.5

TEXTURE AND CALCIUM CARBONATE EXAMPLES
EARLY "PALOUSE" SOIL

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand					% Silt & Clay	$\%CaCO_3$
		Very Coarse	Coarse	Medium	Fine	Very Fine		
299-W18-3 150' Sandy silt	.1	.3	4.3	4.6	5.0	14.2	71.5	2.7
699-35-78 145' Slightly calcareous silty fine to very fine sand	.5	1.1	3.2	12.7	20.4	33.6	28.5	6.8
299-W22-27 120' Slightly silty medium to very fine sand	.1	.9	8.5	26.7	30.0	22.2	11.6	1.5

These sediments are generally compacted and massively bedded with no observable internal laminations or cross-stratification. A reworking of upper Ringold material is suggested and any coarser sands were either not available in the source area or were deposited as sand dunes closer to the source.

A relatively high calcium carbonate content is present in the eolian silt which suggests the deposit contains reworked caliche from the upper Ringold unit and was subjected to semiarid to arid climatic conditions comparable to today. Much of the eolian deposit throughout the study area was apparently stripped by erosion during Pleistocene flooding.

3.5 HANFORD FORMATION

The surface and near-surface sand and gravel in the Separation Areas are the glaciofluvial sediments[4] which form the Hanford Formation (Appendix Figures B.2 through B.8). The Hanford Formation in much of the southern portion of the study area is veneered with 5 to 10 feet of eolian sediments.[7] The thickness of the Hanford Formation varies from 80 feet in the western part of the Separation Areas to a maximum of 350 feet in the eastern part of the study area (Appendix Figure B.6) and is composed of the Pasco Gravels facies.

The uppermost facies of the Hanford Formation throughout most of the study area is a relatively coarse-grained, silty sandy gravel to a gravelly sand (Plates 3 through 12). In general the uppermost Hanford sediments are coarser in the northwest portion of the study area and fine in texture to the south and east.[4,15,21,23,31]

Beneath the upper gravels the sediments are primarily in the sand range, grading from very coarse-to-fine sand in the northwest portion of the study area to slightly silty fine-to-very fine sand in the southwest portion and coarse-to-fine sand in the southern and south-central portions. Gravel units also occur as channel fill in the sand units. In most cases the sediments fine downward with two or three minor textural boundaries (Plates 3 through 8). These facies are laterally continuous and fine to the south and east. Examples of textural and $CaCO_3$ values for the Hanford Formation are given in Table 3.6.

TABLE 3.6

TEXTURE AND CALCUIM CARBONATE EXAMPLES
HANFORD FORMATION

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand Very Coarse	Coarse	Medium	Fine	Very Fine	% Silt & Clay	%$CaCO_3$
299-W11-1 31' Slightly silty pebbly very coarse to coarse sand	21.6	22.6	19.4	12.4	8.1	5.2	10.8	1.6
699-44-64 70' Silty sandy medium to fine pebble	43.8	10.3	18.7	10.8	5.8	3.5	7.2	1.3
299-E27-5 220' Coarse to fine sand	.6	4.8	26.5	44.6	13.7	4.1	5.6	.9
299-E28-15 120 Slightly silty coarse to medium sand	3.5	11.6	22.9	30.5	13.2	7.1	11.2	2.4
299-E28-6 45' Very coarse to medium sand	2.4	16.5	47.9	19.1	5.9	4.6	3.7	1.7

9 2 1 2 5 6 1 0 6 9

The Hanford Formation is generally composed of less than 50 percent basalt fragments (Appendix Table E.3) with the highest percentage of basalt occurring in the pebble and larger size range. A high percentage of basalt often indicates proximity to basalt outcrop. The non-basaltic pebble and larger fraction consists of quartzite, granite, granite porphyry, diorite and diorite porphyry with minor constituents of gneiss, schist and pebble-chert conglomerate.

The sand fraction is composed primarily of quartz and feldspar (orthoclase and plagioclase) with some samples containing greater than 10% pyroxene and amphibole, mica, chlorite, ilmenite and magnetite (Appendix Table E.2). The silt- and clay-sized fractions are composed of quartz, feldspar, mica and smectite (Appendix Table E.1).

Many varied bedding forms have been observed in the Hanford Formation.[34] Information on bedding forms in the Separation Areas is obtained from excavations for waste facilities, open sand and gravel pits, and observations during drilling operations. The best observations are from excavations and data are, therefore, biased by the location and depth of recent major excavations.

Bedding forms are significant in that they are current direction indicators, the current direction being down dip, and the types of cross bedding reflect the depositional environment. Unsaturated flow in vadose zone sediments is partially controlled by bedding. Horizontal bedding with fine laminations impedes downward migration and promotes lateral spreading while cross-bedded units enhance downward migration along bedding planes.

Sediments in the Hanford Formation have been observed as massively bedded units showing no apparent stratification, horizontally bedded often with fine laminations, cross bedded with various types of cross bedding and as graded-bed sequences.[34]

Gravels exposed in solid waste burial trenches in the northwestern part of 200 West Area display steeply dipping cross-beds or foreset beds dipping to the south-southeast between 25 and 40 degrees (Figure 3.9). The gravels are composed of pebbles to small cobbles with a sand matrix. These steeply dipping coarse sediments were deposited on the lee side of bars or very large coarse-textured ripples.[34,35] The coarse pebbles

FIGURE 3.9

FORESET BEDS IN HANFORD FORMATION - HANFORD SITE and cobbles made up the bed load with sand size particles carried in suspension near the bed of a high energy fluvial system and were deposited on the lower energy environment of the lee slope. Current direction during deposition was from the north-northwest.

Gravel exposed between 200 East and 200 West areas and in 200 East Area are bedded at an angle of 15 to 20 degrees to the south-southeast and often have horizontally bedded gravels above and below the dipping beds. It is not uncommon to find areas of foreset-bedded sand within the gravel units. Limited exposures, both laterally and vertically, severely limit the ability to make generalities about the overall bedding and depositional environment of the gravel unit. It is apparent that during the last phases of flooding major current channels were flowing across the study area from the north-northwest.

Massive bedding with no apparent stratification, horizontal fine bedding with discontinuous laminae, various types of cross-bedding and graded-bed sequences have all been observed in the sand facies of the Hanford Formation.

Observations made during cable-tool drilling in B-Plant area suggest that the sand was not apparently bedded except for infrequent stringers of silt. Most beds which appear to be massive do show laminations or cross laminations upon microscopic inspection, but a general absence of bedding suggests rapid deposition from suspension or deposition from a highly particle charged fluvial system.[36]

Sand units throughout 200 West Area and around the Purex facility are finely bedded and contain discontinuous laminae (Figure 3.10). The laminae are generally composed of nearly horizontal layers parallel to the plane of stratification. Horizontal bedding of sands is produced during a high flow regime when ripples, dunes and bars of lower energy environments are sheared off and deposition takes place on a relatively smooth surface.

Also present in Hanford Formation sands is cross stratification in which the strata are inclined, usually between 15 to 30 degrees. Cross-bedding is produced by deposition on the lee slope of ripples, dunes, sand waves and bars, all common bedforms in fluvial environments. Steeply dipping, or foreset beds, are formed on the lee of large sand waves or bars. These tabular bodies usually have horizontally bedded sands above and below (Figure 3.11). Smaller cross-bedded units are present and produced by deposition on the lee of ripples and small dunes (Figure 3.12). Low-angle bedding occurs when sediments are being deposited on a relatively smooth surface, often from high velocity and deep water.

Graded bedding sequences, grading from fine to coarse, were observed in the 241-SY Tank Farm excavation and are shown in Figure 3.13. This type of reversed graded bedding is relatively uncommon, usually related to deposition by fluvial systems with a high sediment content in a high energy environment.

Clastic dikes have been identified in the Hanford Formation in the 241-SY Tank Farm excavation (Figure 3.14) and during cable-tool drilling operations. These sedimentary structures are planar features and are discordant to planes of stratification. They are commonly wedge-shaped in cross section and filled with clay-to-gravel sized clastic sediments which are often nearly vertically bedded. Within the Pasco Basin the surface lateral extent of clastic dikes is commonly expressed as patterned ground. However, in the Separation Areas exposures of patterned ground have not been observed. Mapping of the lateral extent of clastic dikes in the subsurface has not been possible due to: (1) the relatively wide well spacing in the Separation Areas, (2) the difficulty in identifying clastic dikes in the subsurface, and (3) the lack of oriented samples for determining the lateral continuity of the clastic dikes. The origin of clastic dikes is not known, but many of the dikes observed in the Pasco Basin appear to represent cracks which are filled with sediments from above. The significance of clastic dikes to waste management operations is that these features affect the movement of water in the vadose zone, generally enhancing the downward movement of soil moisture.

The glaciofluvial Hanford Formation was deposited by multiple catastrophic Pleistocene floods.[5,37,38,39] The sediments in the Separation Areas form a giant bar that was built when unusually large volumes of sediment-charged water flowed through the Pasco Basin.[4] Floodwater entering the Pasco Basin through Sentinel Gap was deflected by Umtanum Ridge and formed a large bar southeast of the Umtanum Ridge.[5,8,40] The main current apparently flowed north of the

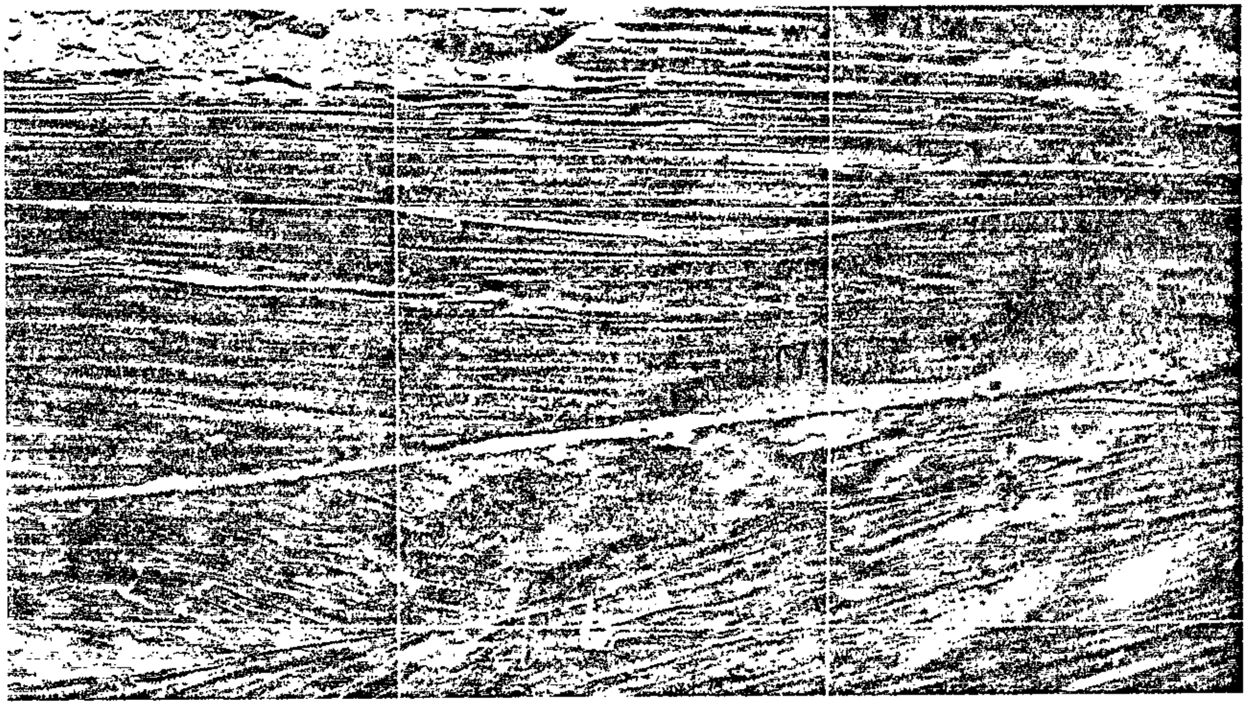

FIGURE 3.10

FINELY BEDDED SAND IN THE
HANFORD FORMATION, 241-SY TANK FARM EXCAVATION

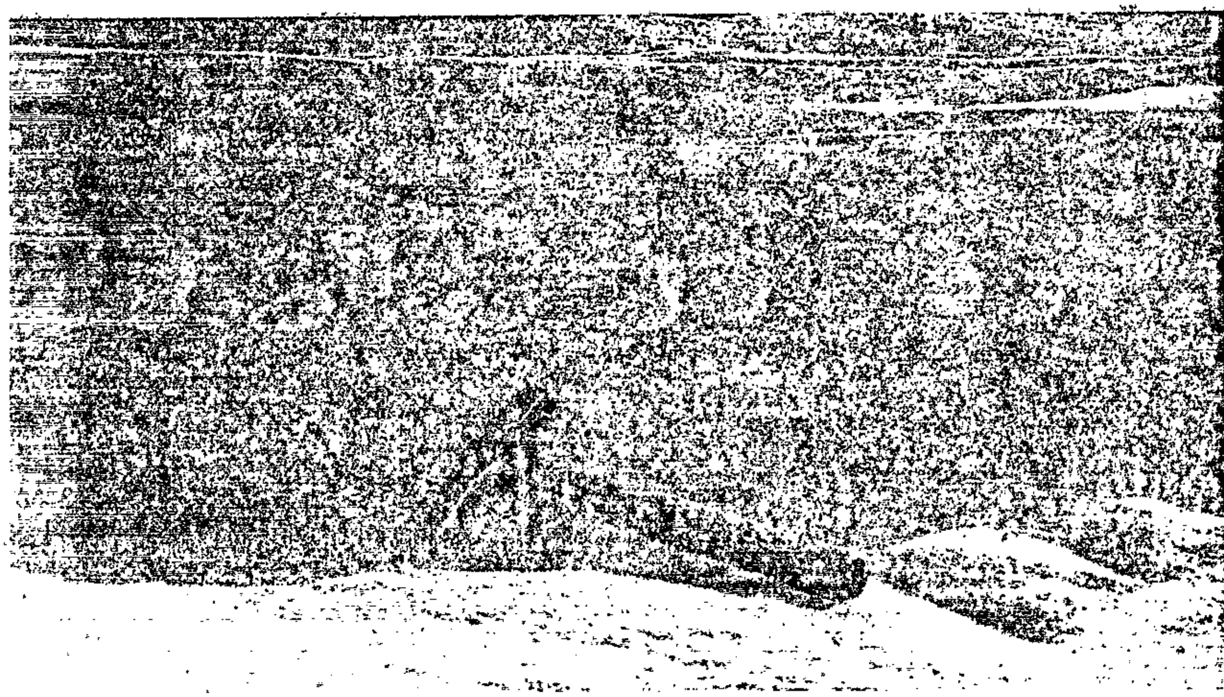

FIGURE 3.11

FORESET BEDDED SAND IN THE
HANFORD FORMATION, 241-SY TANK FARM

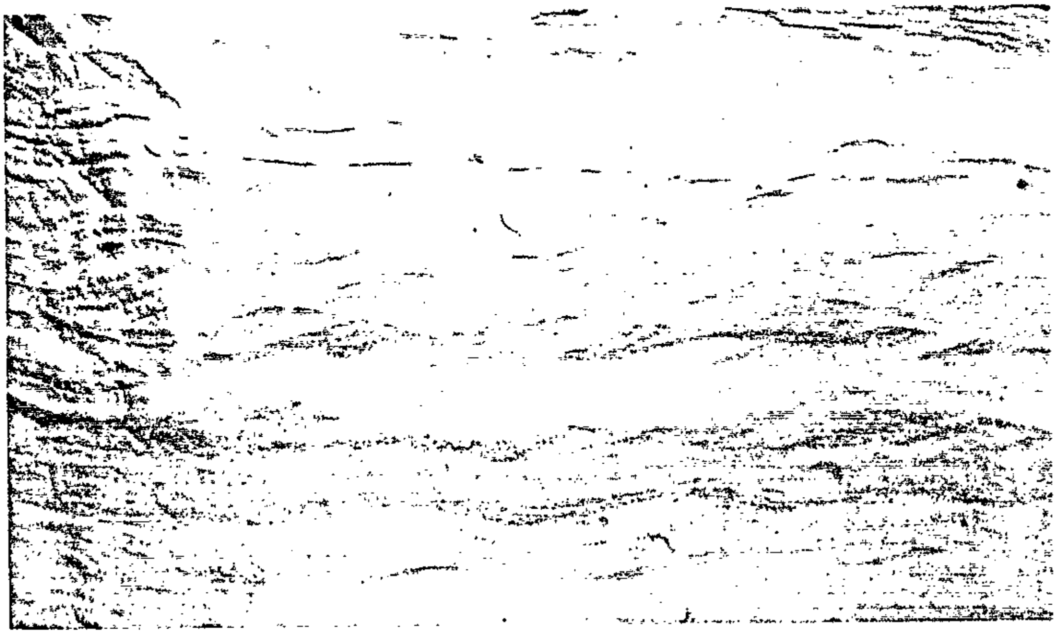

FIGURE 3.12

SMALL SCALE CROSS BEDDING IN
HANFORD FORMATION 202-A TUNNEL EXCAVATION

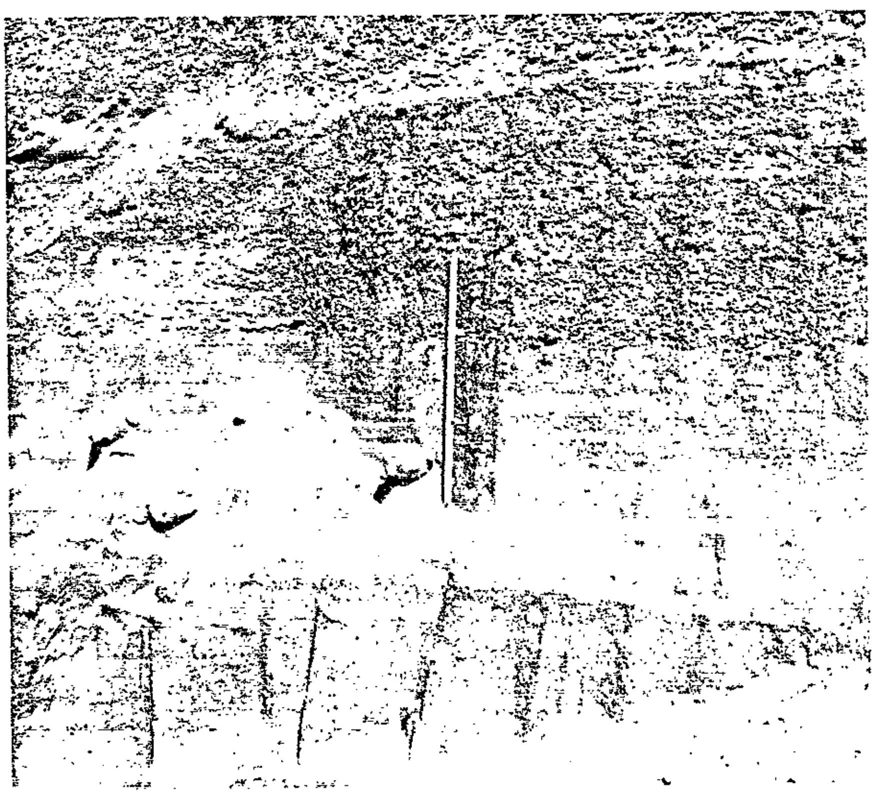

FIGURE 3.13

GRADED BEDS IN THE 241-SY TANK
FARM EXCAVATION

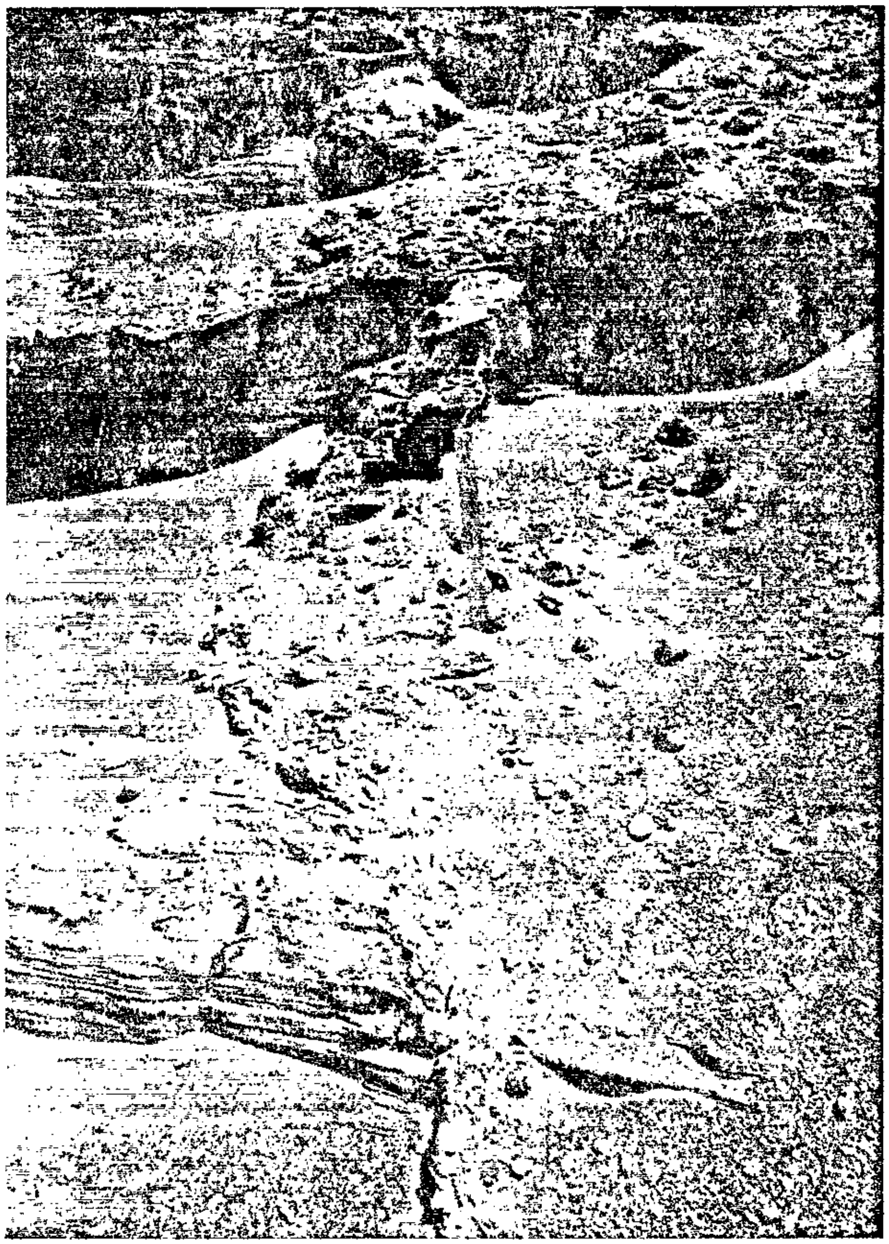

FIGURE 3.14

CLASTIC DIKE IN THE
241-SY TANK FARM EXCAVATION

Umtanum-Gable Mountain Structure with some side current flow between Gable Mountain and Gable Butte and between Gable Butte and Umtanum Ridge.(8)

The greater portion of the bar is composed of sand which was deposited south of the main flood current. The fine texture supports the hypothesis that these sediments were deposited away from the main current channel. The early flood waters may have been confined by a more extensive Umtanum-Gable Mountain Structure which was subsequently eroded to its present topography during catastrophic flooding, or the deflection of Umtanum Ridge alone may have deflected the main current to an east-northeast direction. In either case, the water flowing through the study area was of lower energy than the main channel and carried only sand sized particles, probably as a highly concentrated sediment dispersion. The general pattern of coarsening upward indicates slight increases in grain size which may be indicative of a higher water volume or shifting of the main current closer to the study area.

A gravel facies on top of the sand is indicative of a higher energy environment. A channel, 250 feet deep, filled with pebbly very coarse-to-medium sand is located in the northeast corner of the study area (Plate 4). It has a general north-south orientation and reflects a major flood current or channel flowing through that area after deposition of the sand unit. Another channel through 200 West Area (Appendix Figure A.2 through A.4 and Plates 3, 5 and 7) contains silty sandy gravel. This channel forms a topographic low through the 200 West Area (Appendix Figure B.8).(8) During deposition of the gravel facies, high-energy currents or channels were flowing through the study area resulting in many cut and fill structures (Figure 3.15). The more southerly orientation of high energy flow may have been related to minor breaching of the Umtanum-Gable Mountain Structure or higher flood volumes which changed the flow pattern of the floodwaters.

Numerous channels are observed north of the Separation Areas that were occupied during waning flood stages and/or later floods(8) and since this time there has been little alteration of the sediments in the study area.

FIGURE 3.15

CHANNEL CUT AND FILL STRUCTURE
IN THE HANFORD FORMATION, 241-SY TANK FARM EXCAVATION

3.6 SURFICIAL EOLIAN DEPOSITS

Loess deposits veneer much of the Separation Areas. Where they have a thickness of greater than 10 feet, they are shown on Appendix Figures A.2 through A.8. Examples of texture and $CaCO_3$ values are shown in Table 3.7.

TABLE 3.7

TEXTURE AND CALCIUM CARBONATE EXAMPLES
SURFICIAL EOLIAN DEPOSITS

Well Number and Depth Textural Description	%Pebbles & Cobbles	% Sand					% Silt & Clay	$\%CaCO_3$
		Very Coarse	Coarse	Medium	Fine	Very Fine		
699-35-70 5' Silty fine to very fine sand	0.4	1.5	9.0	13.2	23.5	27.7	24.8	1.5
299-W15-14 5' Slightly silty fine to very fine sand	0.1	1.9	6.4	12.7	31.4	32.6	14.8	2.0

Small sand dunes are present in the southern portion of the study area where they overlie Hanford sediments of comparable texture. These deposits are not delineated on the cross sections as it was not possible to determine their vertical extent on the basis of cable-tool well sample textures.

The eolian deposits are composed of reworked Hanford Formation sediments and have the same mineralogical composition as the fine-textured fractions of those sediments. Volcanic ash has been observed in some eolian sand deposits in the Separation Areas.

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4.0 GEOMORPHOLOGY

4.1 INTRODUCTION

The Hanford Site is situated in the topographic depression of the Pasco Basin (Figure 1.1). The Basin is bounded by basaltic ridges to the north, west and south and by a monoclinal structure to the east; and contains a thick sequence of Pliocene and Pleistocene sediments. The geomorphology of the interior of the Basin is dominated by flood bars and channels formed during Pleistocene catastrophic flooding of the Basin. Subsequent to flooding the major geomorphic process within the Basin interior has been eolian deflation and deposition. This has resulted in large dune fields and a loess mantle of variable thickness.

4.2 SITE GEOMORPHOLOGY

The Separation Areas are situated on a large flood bar (Appendix Figure B.8). This flood bar, referred to as an expansion bar,[1] was aggraded by lateral accretion from a main flood current channel which flowed in an easterly direction north of the study area. At this time, primarily sand-sized sediments were deposited. During a later stage of flooding, floodwaters flowed through the eastern portion of the study area downcutting into the sand-sized sediments, and filled the channel with sandy gravel (Appendix Figures A.2, A.3, A.4 and A.7; Plates 4, 6, 8, and 11). This channel is shown cutting the middle Ringold unit in the northeastern portion of 200 East Area. Another channel flowed in a southerly direction through 200 West Area and remains as a topographic depression on the present day land surface (Appendix Figure B.8).

As floodwaters receded channels developed at lower levels and were later abandoned or captured by actively downcutting streams. A network of abandoned stream channels has been defined north of the study area.[1] In the northern part of the study area one such channel meanders[2] along the boundary and is shown as a depression in Appendix Figure B.8.

The low annual precipitation in the Pasco Basin and the high permeability of the surface sediments has resulted in very little post-flood alteration of the topography by fluvial processes. Deserttype vegetation and strong winds have resulted in major alteration by eolian processes. Blowouts and dunes occur in the southern part of the study area and a veneer of loess has been deposited throughout the study area.

4.3 PALEOTOPOGRAPHY

Following deposition of the upper Ringold unit, the ancestral Columbia River eroded much of the upper unit throughout the Basin interior. A remnant of upper Ringold unit is present in 200 West Area where it commonly contains one or more caliche horizons. This paleosurface is covered by the early "Palouse" soil.

The middle Ringold surface in 200 West Area (Appendix Figure B.4) is illustrative of the topography prior to deposition of the upper Ringold unit. Elsewhere the middle Ringold surface was eroded by normal fluvial processes and by Pleistocene floodwaters.

The only major definable channel in the Ringold Formation is in the northeast corner of the study area where a paleochannel cuts deeply into the basalt bedrock (Appendix Figure B.2). An antecedent stream which occupied this channel kept pace with the uplift of the Umtanum-Gable Mountain structure, deeply incising into the basalt. Additional regional work is required to determine when and for how long the stream occupied this channel. During Pleistocene flooding, Ringold sediments were eroded from the channel and Hanford sediments were deposited.

During the time of deposition of the lower Ringold unit, the paleoslope of the Separation Areas was to the southwest, reflecting the slope of the limb of the Umtanum-Gable Mountain Structure. In the areas of deposition of the lower silt and sand unit, the low energy environment is interpreted to be nearly horizontal with sedimentation keeping pace with deformation, syndepositional folding. This is evidenced by a thickening of lower Ringold sediments in the deepest depressions of the Cold Creek Syncline.[3] The present gently southwesterly dipping surface of the lower Ringold unit is indicative of post-depositional deformation.

The rather consistent thickness of the basal Ringold unit in the study area suggests that the topography during the deposition of this unit was relatively flat and that major deformation of the Cold Creek

Syncline occurred during and/or after deposition of this unit. The sedimentary sequence suggests that an increased rate of deformation resulted in ponding of water and a change from a gravel unit to the silt and sand of the lower Ringold unit.

4.4 REFERENCES

1. K. R. Fecht, Geology of Gable Mountain-Gable Butte Area, RHO-BWI-LD-5, Rockwell Hanford Operations, Richland, Washington (1978).

2. J. T. Lillie, A. M. Tallman, and J. A. Caggiano, Preliminary Geologic Map of the Late Cenezoic Sediments of the Western Half of the Pasco Basin, RHO-BWI-LD-8, Rockwell Hanford Operations, Richland, Washington (1978).

3. R. C. Routson and K. R. Fecht, Soil (Sediment) Properties of Twelve Hanford Wells, RHO-LD-82, Rockwell Hanford Operations, Richland, Washington (In Review).

GLOSSARY

Antecedent stream - A stream that was established before local uplift or diastrophic movement was developed across it and that maintained its original course after and in spite of the deformation by incising its channel at approximately the same rate as the land was rising; a stream that existed prior to the present topography.

Anticline - A fold, the core of which contains the stratigraphically older rocks; it is convex upward.

Caliche - A term applied broadly to an opaque reddish-brown to buff or white calcareous material of secondary accumulation (in place), commonly found in layers on, near or within the surface of stony soils of arid and semiarid regions, but also occurring as a subsoil deposit in subhumid climates. It is composed largely of crusts or succession of crusts of soluble calcium salts, primarily calcium carbonate, in addition to impurities such as gravel, sand, silt and clay.

Clast - An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering (disintegration) of a larger rock mass.

Conformable - Said of strata or stratification characterized by an unbroken sequence in which the layers are formed one above the other in parallel order, by regular, uninterrupted deposition under the same general conditions; also said of the contacts (abrupt, gradational or intercalated) between such strata. The term is often applied to a later formation having bedding planes that are parallel with those of an earlier formation and showing an arrangement in which disturbance or erosion did not take place at the locality during deposition.

Curie - A unit of measurement of radioactivity, defined as the equivalent of 3.7×10^{10} disintegrations per second, which is approximately equal to the radioactivity of one gram of radium.

Detritus - A collective term for loose rock and mineral material that is worn off or removed directly by mechanical means, as by disintegration or abrasion; especially fragmental material, such as sand, silt and clay, derived from older rocks and moved from its place of origin.

Doubly-plunging fold - A fold, either an anticline or syncline that reverses its direction of plunge within the observed area.

Eolian - Pertaining to the wind; especially said of rocks, soils and deposits (such as loess, dune sand and some volcanic tuffs) whose constituents were transported (blown) and laid down by atmospheric currents, or of land forms produced or eroded by the wind, or of sedimentary structures made by the wind, of geologic processes accomplished by the wind.

Ephemeral stream - A stream or reach of a stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

Facies change - A lateral or vertical variation in the lithologic or paleontologic characteristics of contemporaneous sedimentary deposition. It is caused by, or reflects, a change in the depositional environment.

Fluvial - Produced by the action of a steam or river - the term is used by geologists especially in regard to river flow and river action.

Geophysical logs - A log obtained by lowering an instrument into a borehole or well and recording continuously on a meter at the surface some physical property of the rock material being logged, i.e., electric log, radioactivity log, sonic log, temperature log, etc.

Glaciofluvial - In this report, the term applies to Pleistocene catastrophic flood deposits.

Hydration - The process by which water combines chemically with other elements.

High-level waste - (a) Those aqueous wastes resulting from the operation of the first cycle solvent extraction system or equivalent, and concentrated waste from subsequent extraction cycles or equivalent in a facility for reprocessing reactor fuel. In addition, all other radioactive liquid not described in low-level waste shall be handled as high-level radioactive waste. (b) All solids (including fuel elements not intended for reprocessing) which require shielding for emplacement in burial grounds or repositories.

Imbrication - The slanting, overlapping arrangement of tabular or platy fragments or flat pebbles in a stream bed or on a beach, in the manner of tiles or shingles on a roof. It is caused by flowing water.

Indurated - Said of a compact rock or soil hardened by the action of pressure, cementation and heat.

Intercalated - Said of layered material that exists or is introduced between layers of a different character; especially said of relatively thin strata of one kind of material that alternates with thicker strata of some other kind of material, such as sediments that are intercalated with basalt flows.

Intrusion - The process of emplacement of magma in pre-existing rock; magmatic activity; also, the igneous rock mass so formed within the surrounding rock.

Isopach Map - A map that shows the thickness of a bed, formation, sill or other tabular body throughout a geographic area.

Lacustrine - Pertaining to, produced by, or formed in a lake or lakes; e.g. "lacustrine sands" deposited on the bottom of a lake; or a "lacustrine terrace" formed along the margin of a lake.

Lamina - The thinnest or smallest recognizable unit layer of original deposition in a sediment or sedimentary rock, differing from other layers in color, composition or particles size, and resulting from variations in the rate of supply or deposition of different material during a momentary or local fluctuation in the velocity of the depositing current; specifically such a sedimentary layer less than 0.4 inch thick. Several laminae may constitute a bed.

Lithofacies Map - A facies map based on lithologic attributes, showing areal variations in the overall lithologic (textural) character of a given stratigraphic unit. It gives information on the changing composition of the unit throughout its geographic extent.

Loess - A widespread, homogeneous, commonly nonstratified, porous, friable, unconsolidated but slightly coherent, usually highly calcareous, fine-grained, blanket deposit (generally less than 100 feet thick), consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand, generally believed to be windblown dust.

Low-level waste - (1) All radioactive liquid that is below DOE concentration guides from Table II (on an annual basis). (2) Existing radioactive liquid effluent streams; (a) N-reactor effluent to 1301-N crib, (b) B Plant steam and condensate to 216-B-55 and 62 cribs and (c) Purex steam and process condensate and ammonia scrubber waste to 216-A-10 and 216-B-30 and 36 cribs which are currently being discharged to soil columns within the Hanford Site and have been determined to meet ALATEP criteria; (3) All solids which do not require shielding for emplacement in burial grounds or repositories.

Magnetotelluric - An electromagnetic method in which natural electric and magnetic fields are measured, usually the two horizontal electric field components plus the three magnetic field components are recorded.

Matrix - The smaller or finer-grained, continuous material enclosing or filling the interstices between, the large grains or particles of a sediment or sedimentary rock; the natural material in which a sedimentary particle is embedded. The term refers to the relative size and disposition of the particles, and no particular particle size is implied.

Metasediment - A sediment or sedimentary rock which shows evidence of having been subjected to metamorphism.

Metavolcanic - A volcanic rock which shows evidence of having been subjected to metamorphism.

Meteoric - Pertaining to water of recent atmospheric origin.

Miocene - An epoch of the upper Tertiary Period, after the Oligocene Epoch and before the Pliocene Epoch; also, the corresponding worldwide series of rocks.

Monocline - A unit of strata that dips or flexes from the horizontal in one direction only, and is not part of an anticline or syncline. It is generally a large feature of gentle dip.

Parasitic folds - A second-order fold on the limbs or hinge area of a larger (first-order) fold.

Perennial stream - A stream or reach of a stream that flows continuously throughout the year and whose upper surface generally stands lower than the water table in the region adjoining the stream.

Permeability - The property or capacity of a porous rock, sediment or soil for transmitting a fluid without impairment of the structure of the medium; it is a measure of the relative ease of fluid flow under unequal pressure.

Plano-convex - Flat on one side and convex on the other.

Pleistocene - An epoch of the Quaternary period, after the Pliocene Epoch of the Tertiary Period and before the Holocene Epoch; also, the corresponding worldwide series of rocks.

Pliocene - An epoch of the Tertiary Period, after the Miocene Epoch and before the Pleistocene Epoch; also the corresponding worldwide series of rocks.

Potassium-argon age method - (K/Ar) Determination of the age of a mineral or rock in years based on the known radioactive decay ratio rate of potassium-40 to argon-40. Ordinarily, material to be dated must be older than 1×10^6 years.

Rad (millirad = 1×10^{-3} rad) - A dosage of absorbed radiation equal to the absorption of 100 ergs of energy per gram material.

Radionuclide - A radioactive nuclide. The term isotope is loosely used synonymously.

Saturated zone - A subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere.

Stringer - A thin, discontinuous bed.

Syncline - A fold, the center of which contains the stratigraphically younger rocks; it is concave upward.

Subaerial - Occurring in the open air; especially said of conditions and processes (such as erosion) that exist or operate on or immediately adjacent to the land surface, or of features and materials (such as eolian deposits) that are formed or situated on the land surface.

Syndepositional fold - A fold structure that forms contemporaneously with sedimentation. It is a feature associated with sedimentary tectonics.

Thermocouple - A thermo-electric device (couple) used to measure temperature differences.

<u>Tholeiitic</u> - A group of basalts primarily composed of plagioclase, pyroxene and iron oxide minerals as phenocrysts in a glassy groundmass or intergrowth of quartz and alkali feldspar. Little or no olivine is present.

<u>Transuranic</u> - Waste contaminated with alpha-emitting radionuclides (including uranium-233 and daughter products) of long half-life and high specific toxicity, to greater than 10 nanocuries per gram of waste matrix.

<u>Tuff</u> - A compacted pyroclastic deposit of volcanic ash and dust that may or may not contain up to 50 percent sediments such as sand or clay. Tuffaceous - said of sediment containing up to 50 percent tuff.

<u>Unsaturated zone</u> - A subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity; and containing air or gases generally under atmospheric pressure. Also referred to as the vadose zone.

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Appendix A

SEPARATION AREAS

STRATIGRAPHIC CROSS SECTIONS

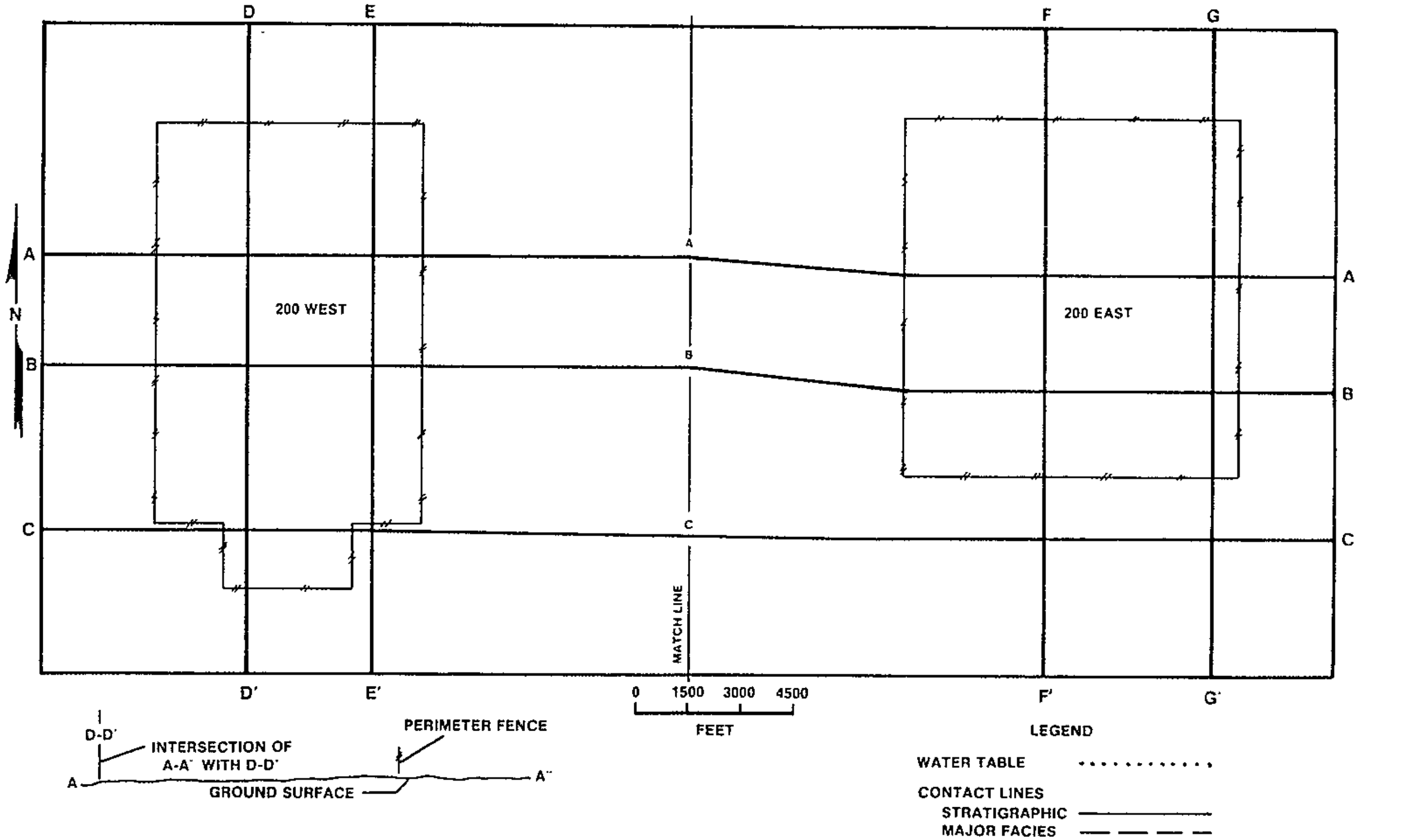

FIGURE A.1

SEPARATION AREAS STRATIGRAPHIC CROSS SECTION
LOCATION MAP AND LEGEND

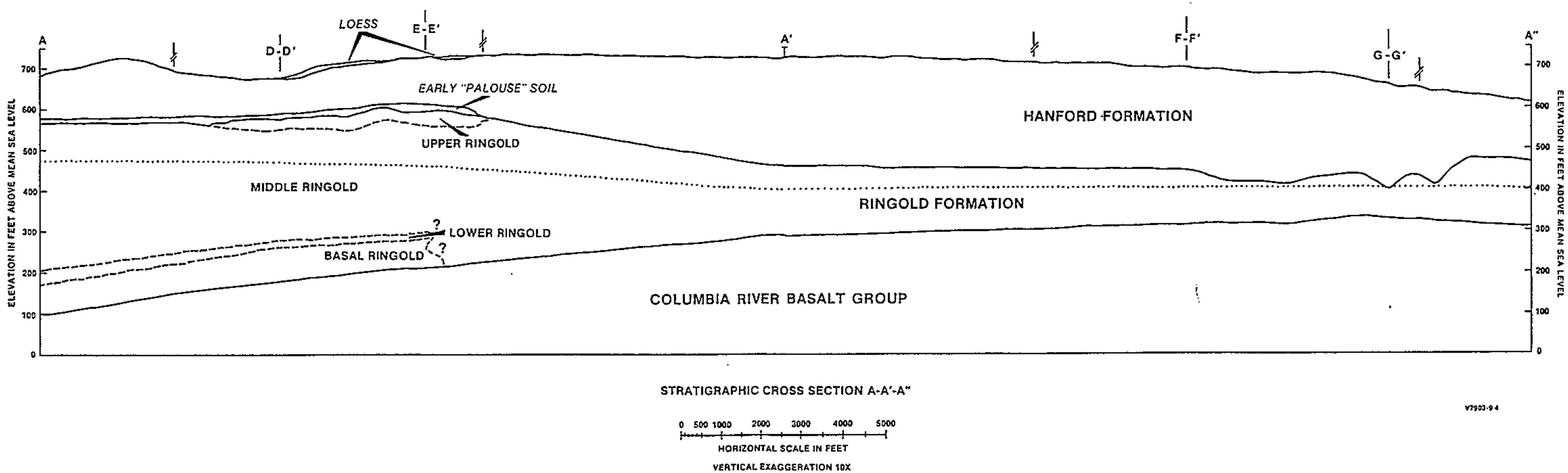

FIGURE A.2

SEPARATION AREAS STRATIGRAPHIC CROSS SECTION A-A'-A"

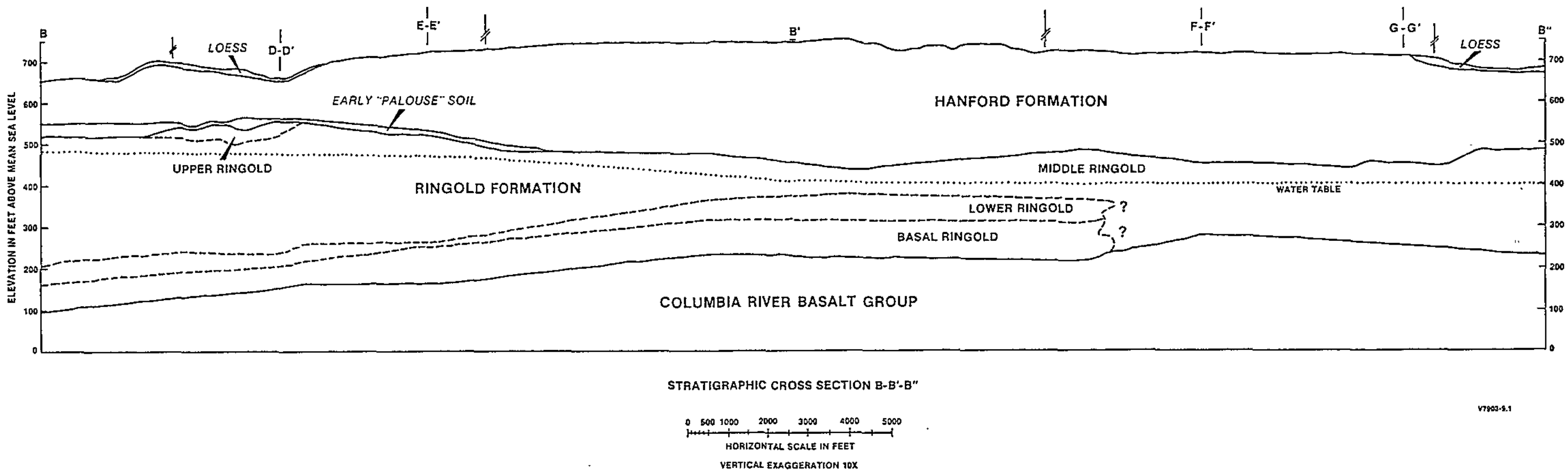

FIGURE A.3

SEPARATION AREAS STRATIGRAPHIC CROSS SECTION B-B'-B"

9 2 1 2 4 6 6 1 0 7 7

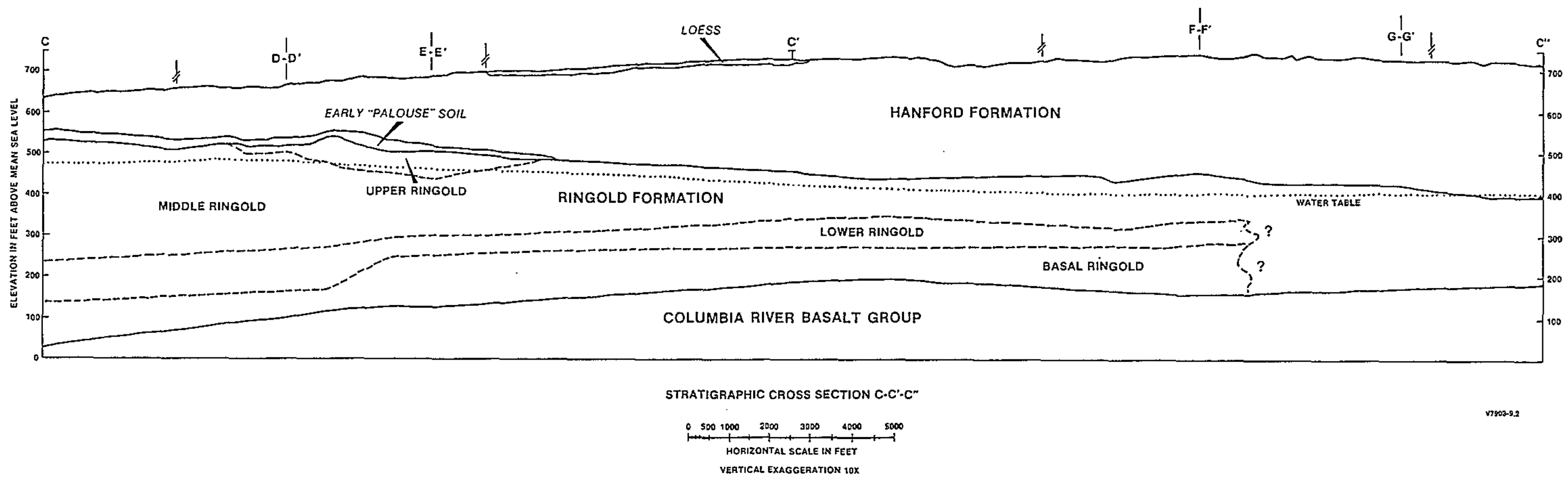

FIGURE A.4

SEPARATION AREAS STRATIGRAPHIC CROSS SECTION C-C'-C"

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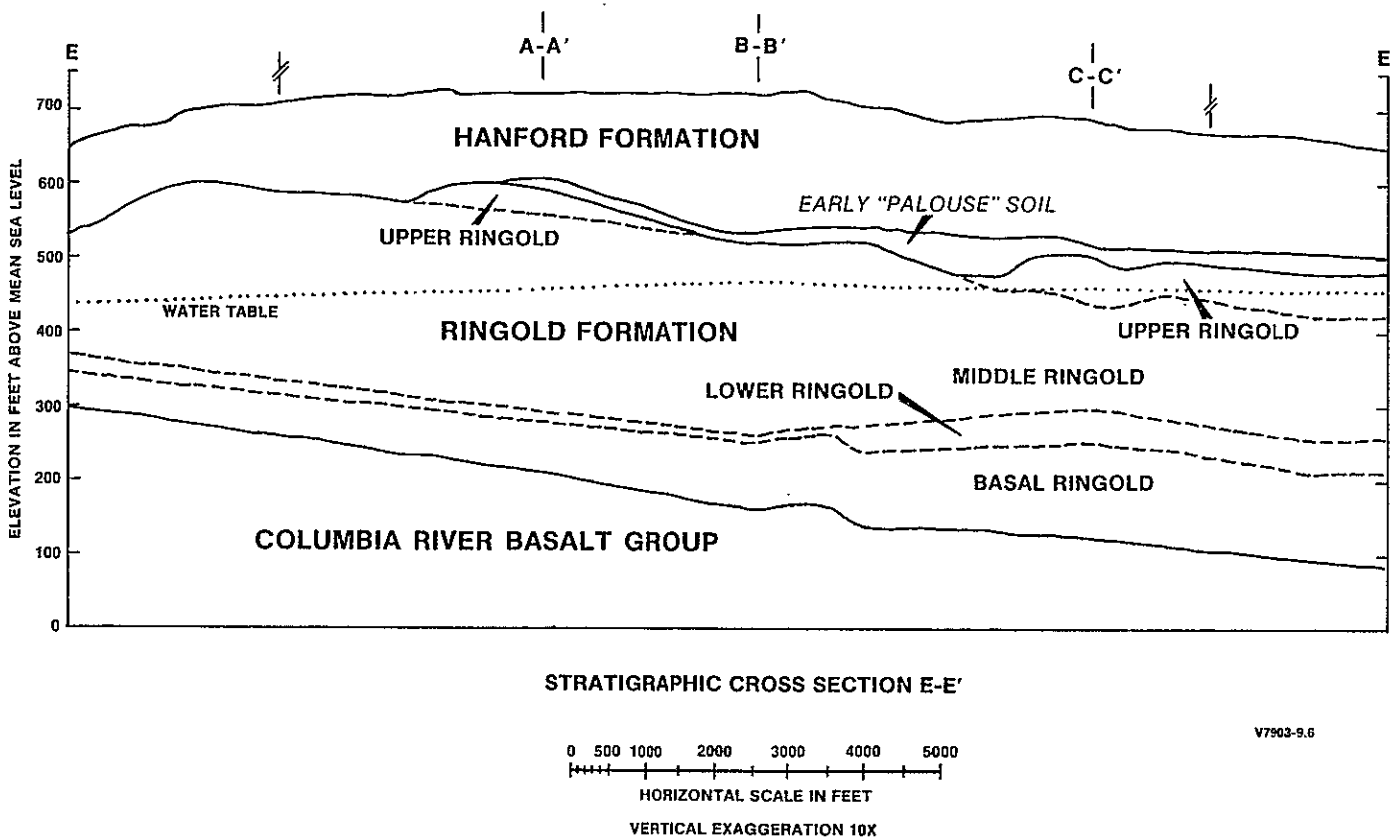
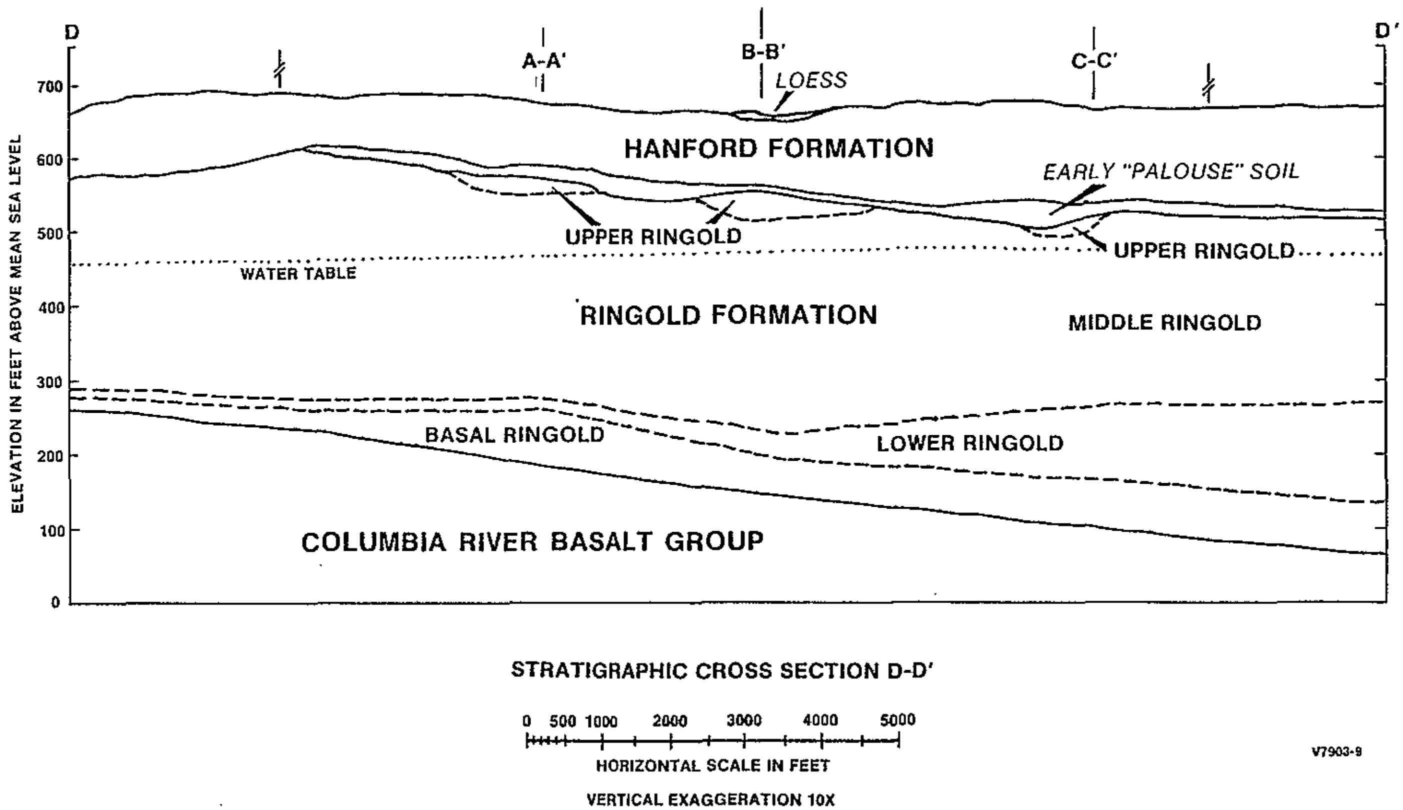


FIGURE A.6

SEPERATION AREAS STRATIGRAPHIC CROSS SECTION E-E'



<u>FIGURE A.5</u>

SEPERATION AREAS STRATIGRAPHIC CROSS SECTION D-D'

9 2 1 2 4 5 6 1 0 8 2

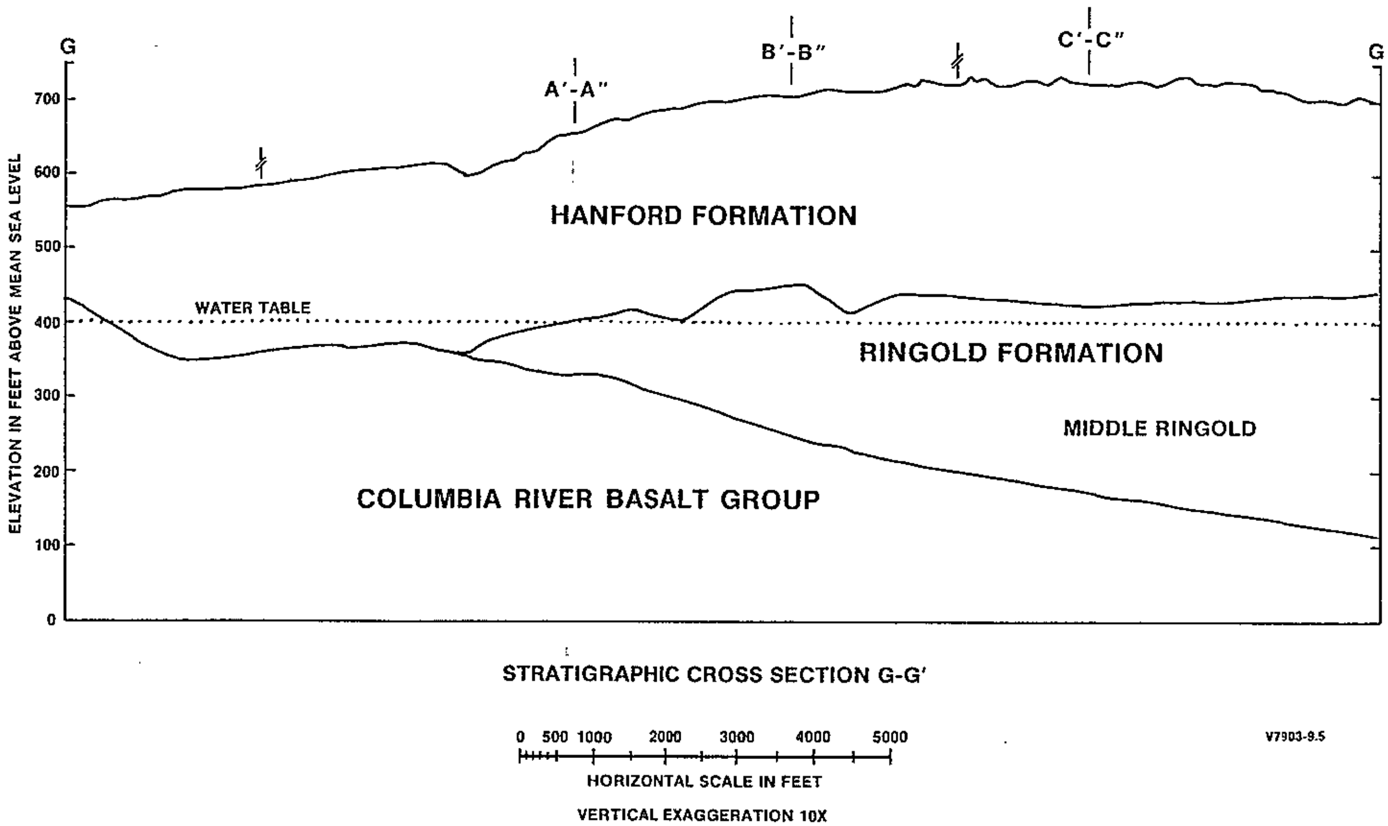


FIGURE A.8

SEPERATION AREAS STRATIGRAPHIC CROSS SECTION G-G'

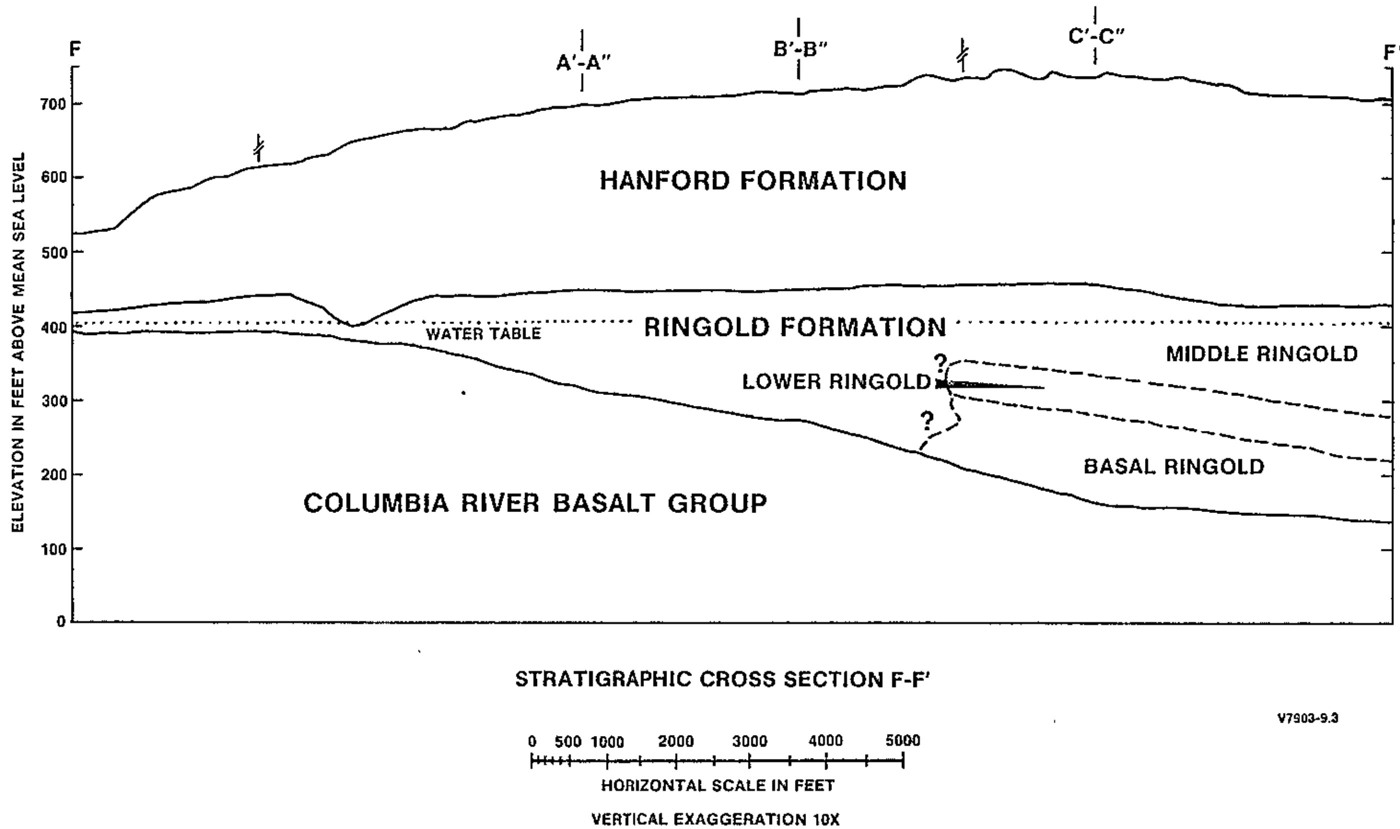


FIGURE A.7

SEPERATION AREAS STRATIGRAPHIC CROSS SECTION F-F'

APPENDIX B

SEPARATION AREAS MAPS

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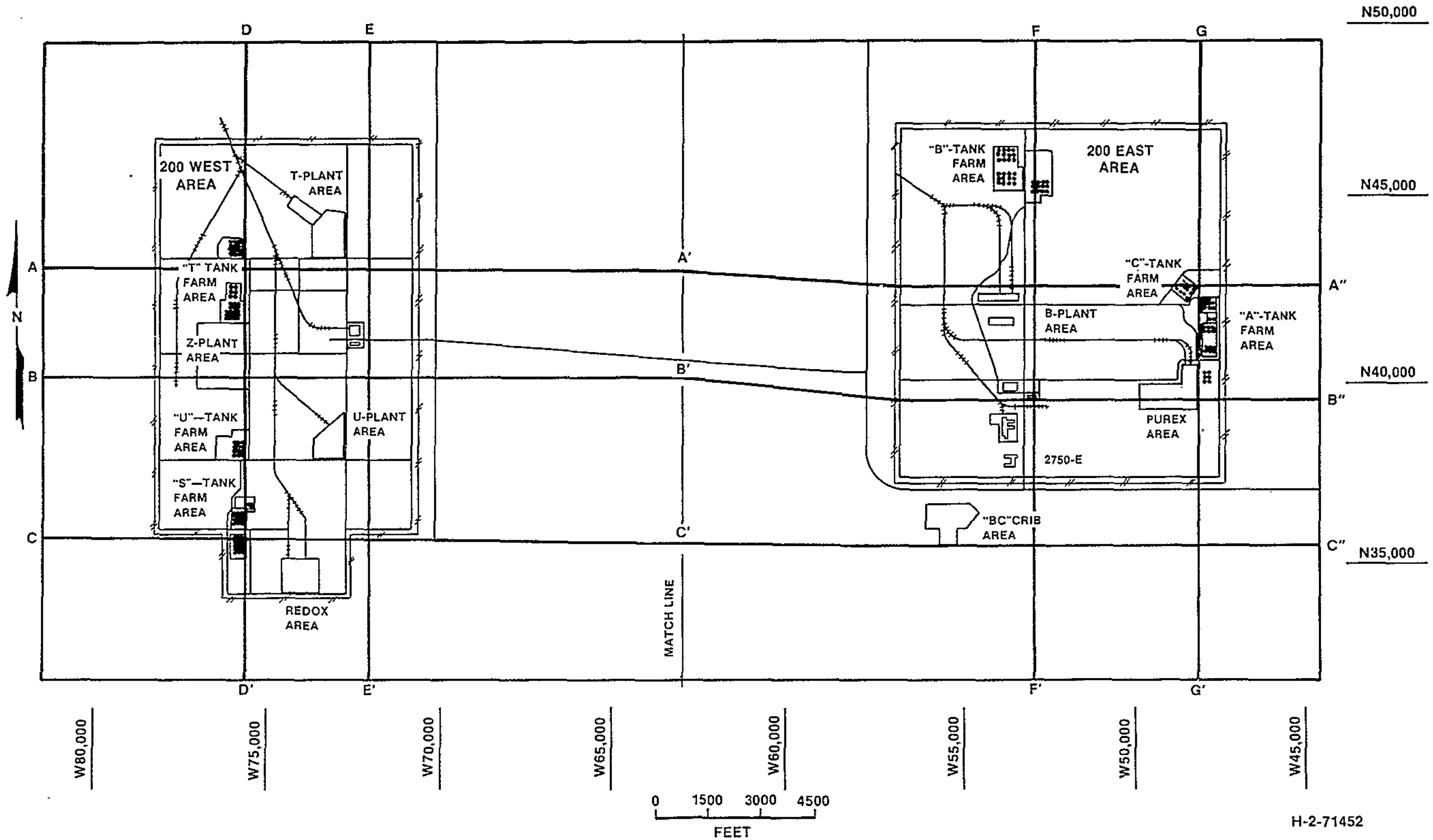
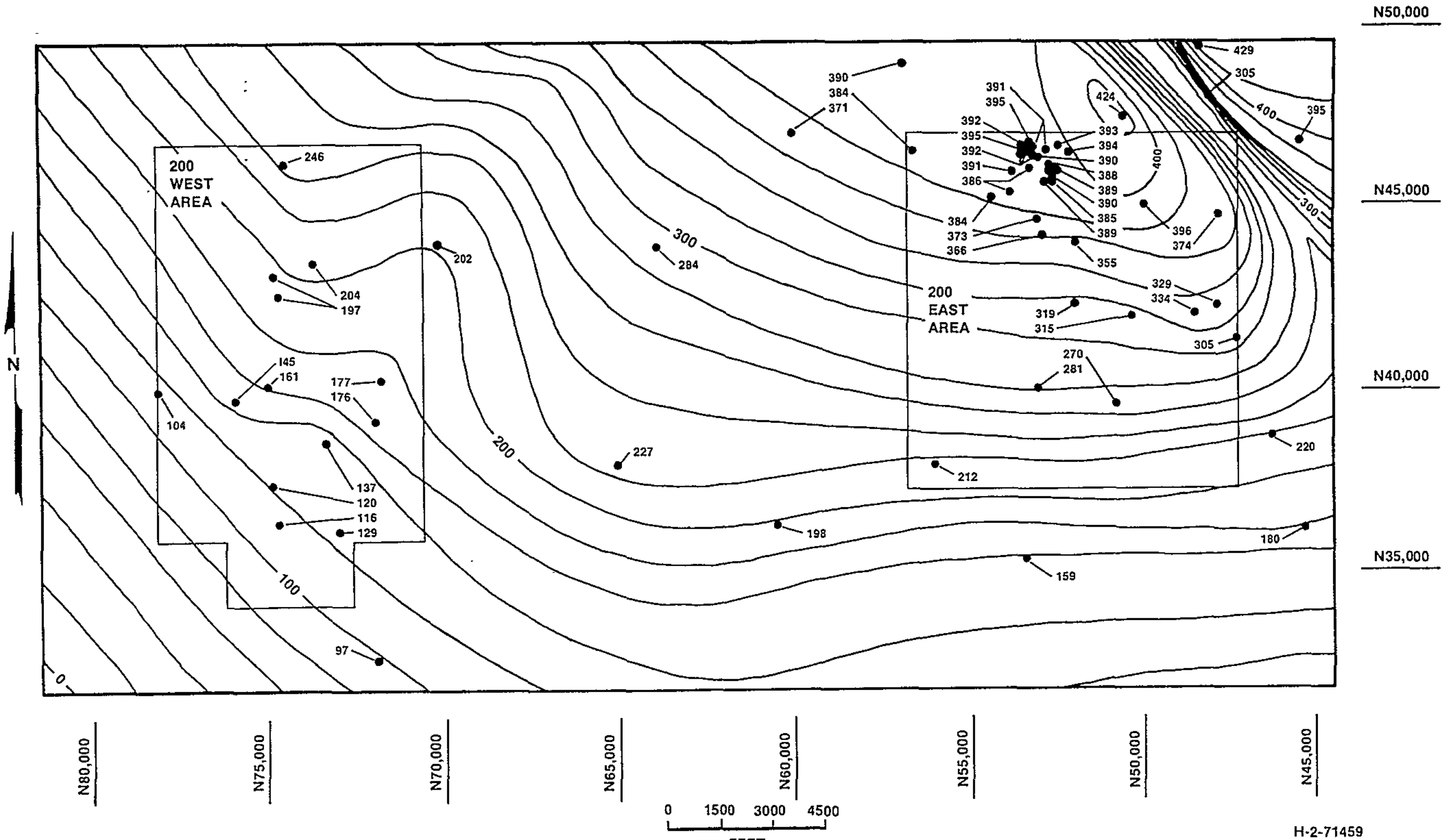


FIGURE B.1

SEPARATION AREAS WASTE MANAGEMENT FACILITIES LOCATION MAP

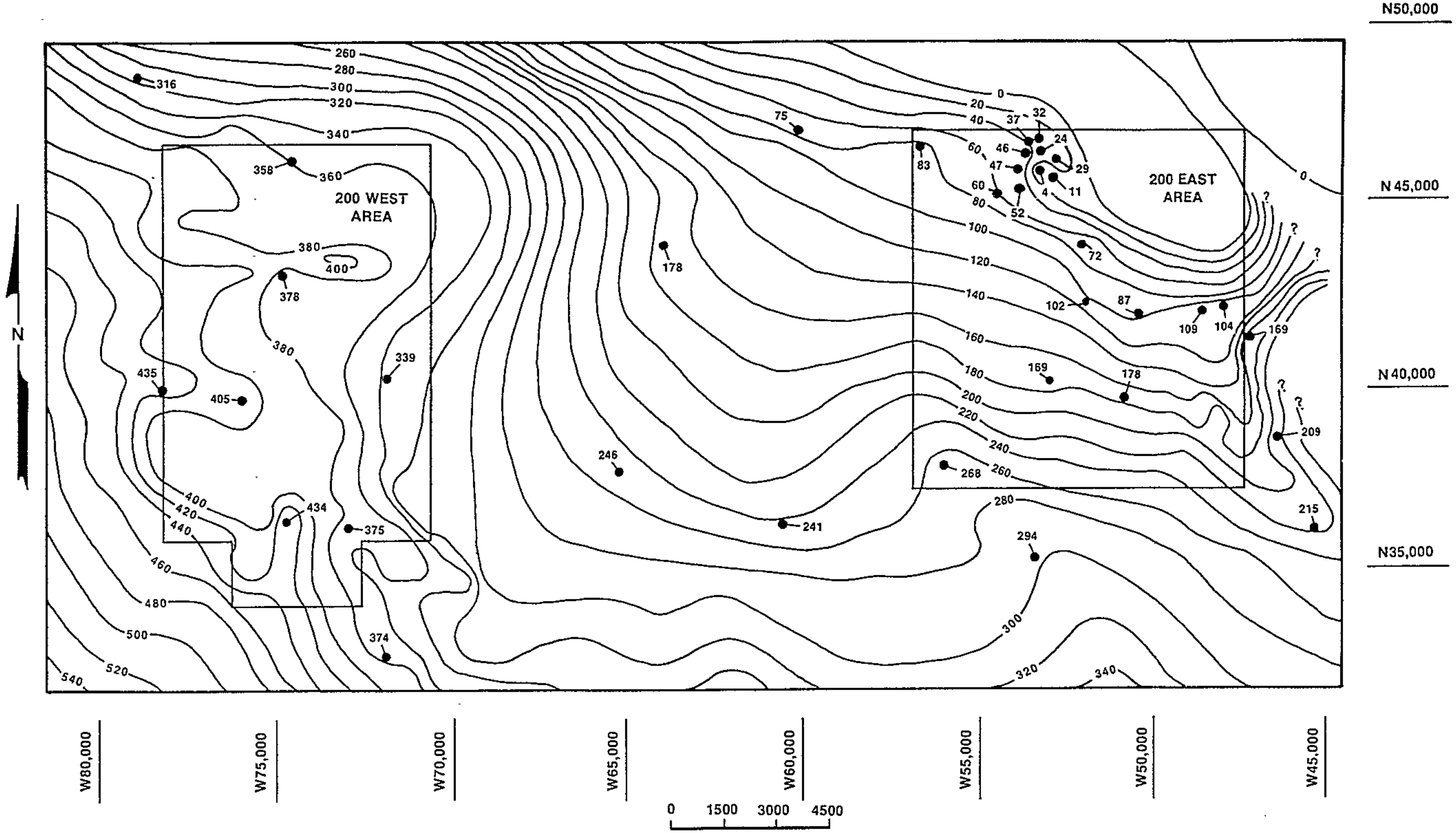
9 2 1 2 4 5 6 1 0 3 5



CONTOUR INTERVAL 20 FEET

FIGURE B.2

SEPARATION AREAS SURFACE OF THE
COLUMBIA RIVER BASALT GROUP MAP



CONTOUR INTERVAL 20 FEET

FIGURE B.3

SEPARATION AREAS RINGOLD FORMATION ISOPACH MAP

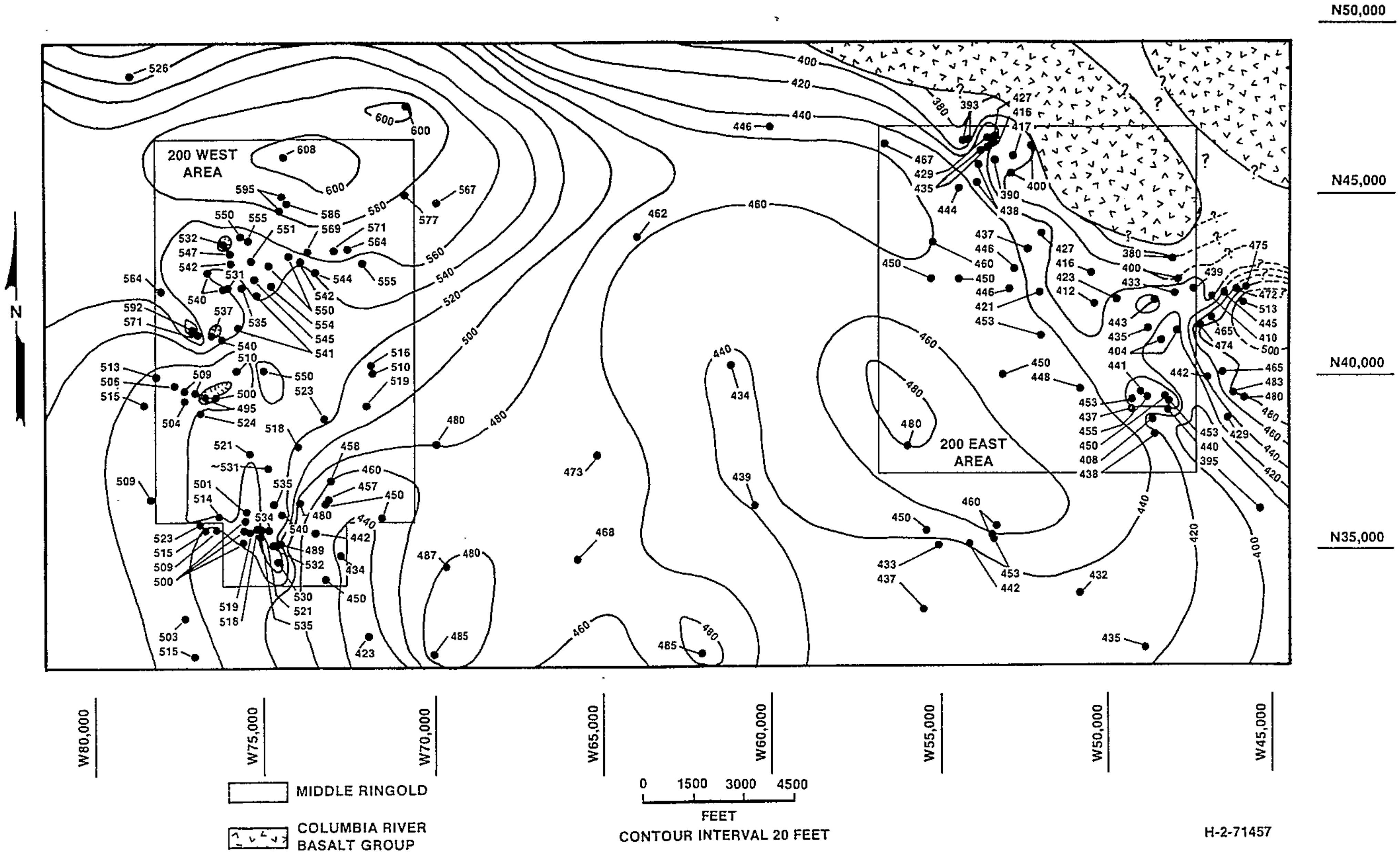


FIGURE B.4

SEPARATION AREAS SURFACE OF THE MIDDLE RINGOLD UNIT MAP

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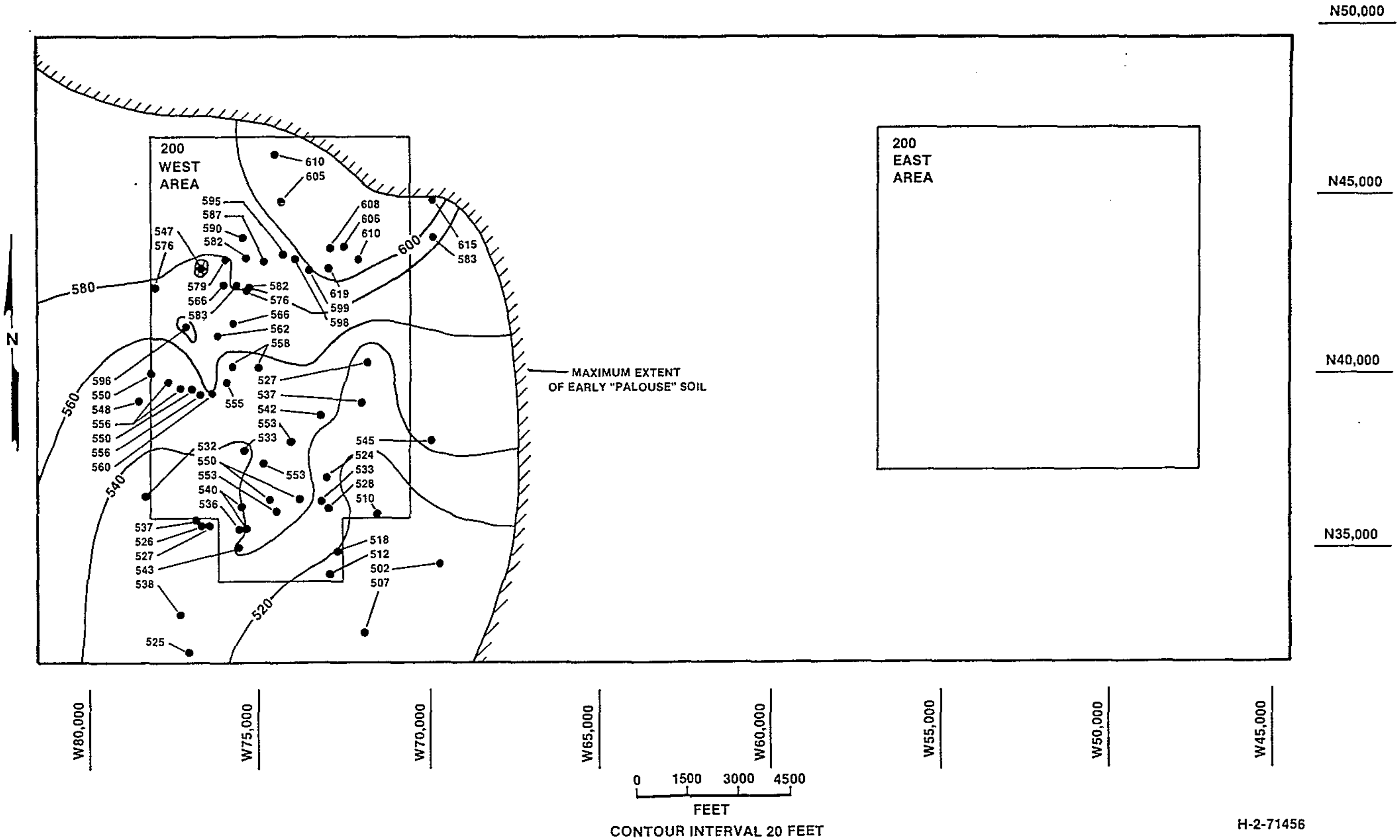

FIGURE B.5

SEPARATION AREAS SURFACE OF THE EARLY "PALOUSE" SOIL MAP

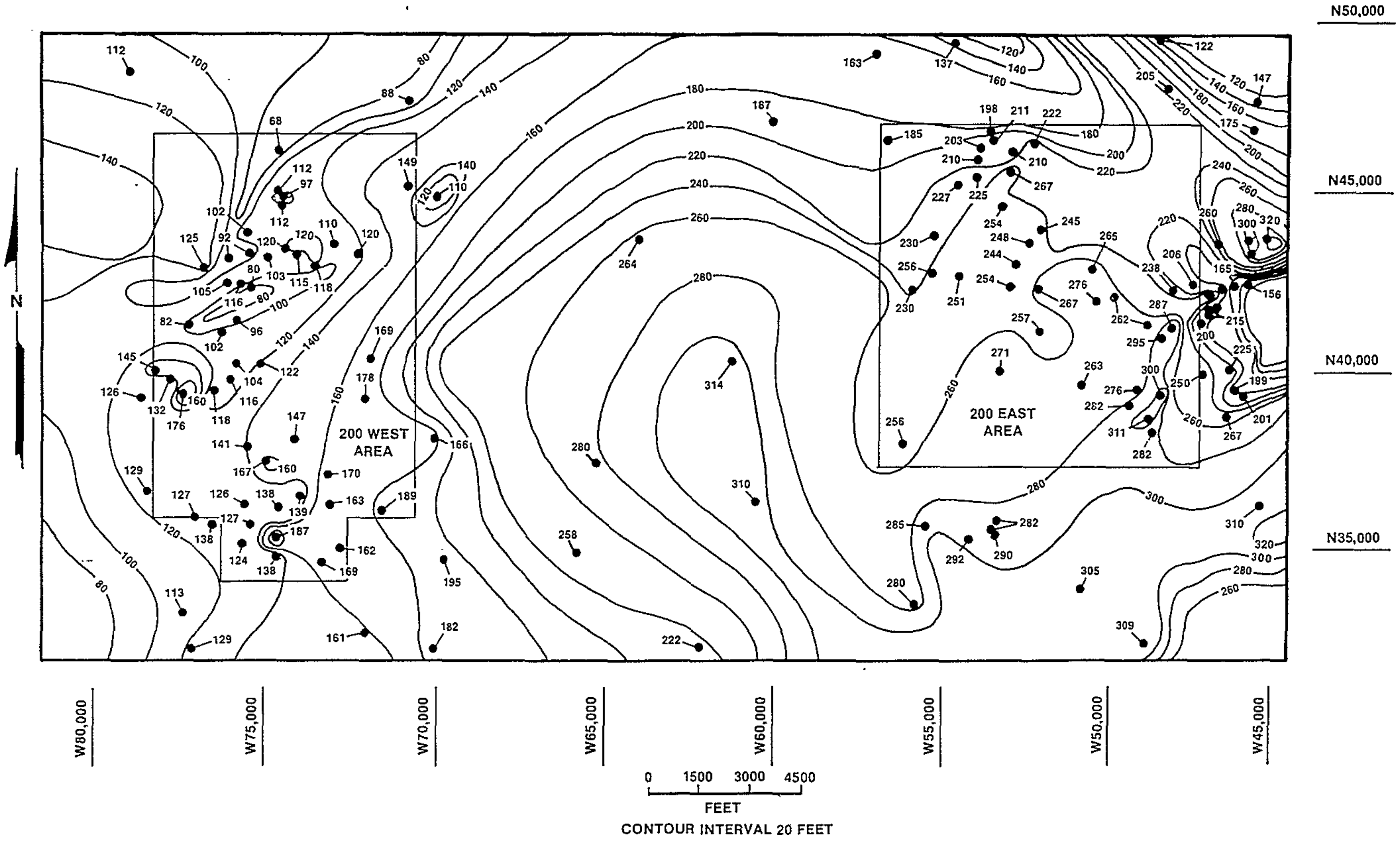

FIGURE B.6

SEPARATION AREAS HANFORD FORMATION ISOPACH MAP

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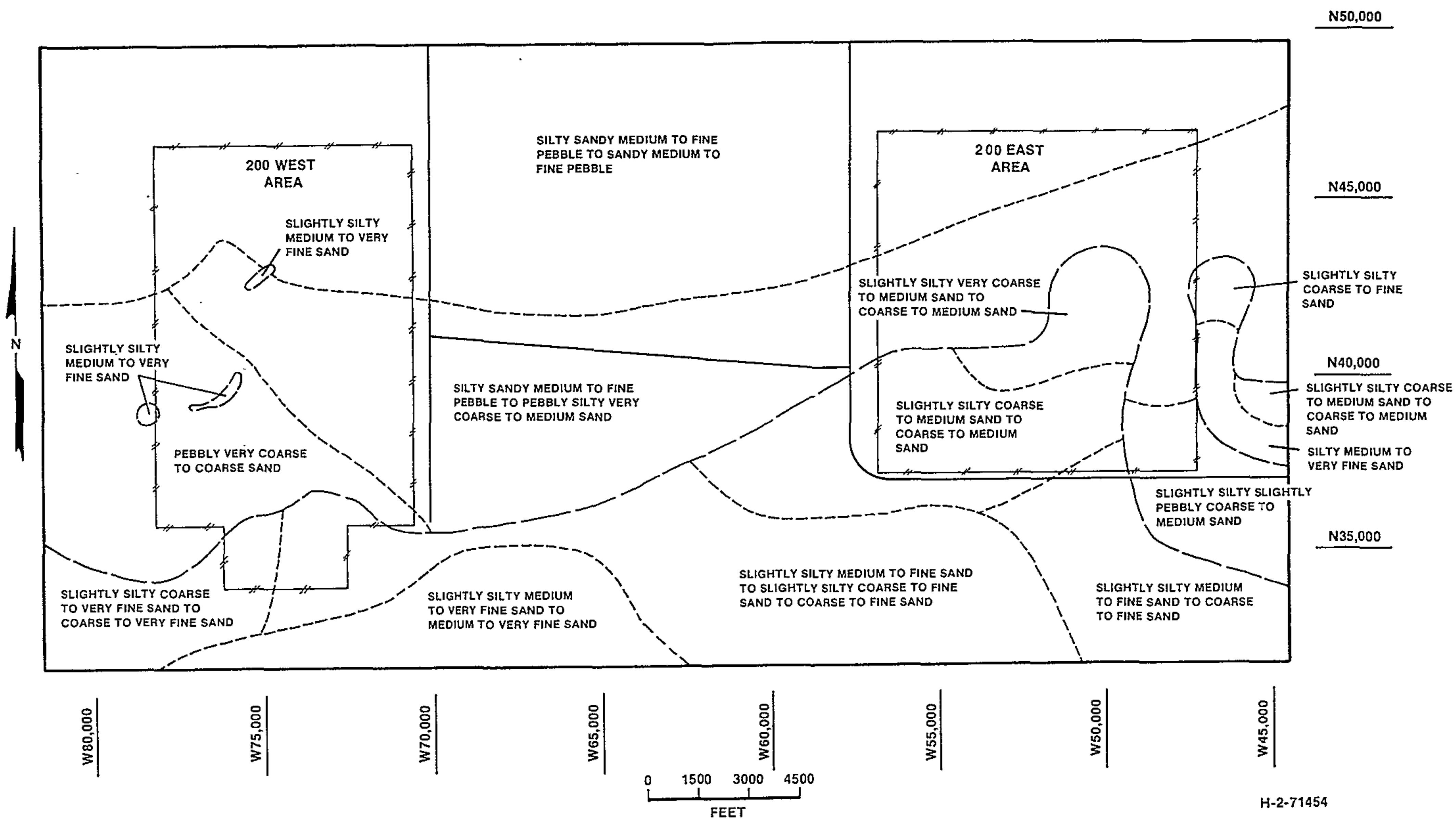

FIGURE B.7

SEPARATION AREAS SURFICIAL GEOLOGY MAP

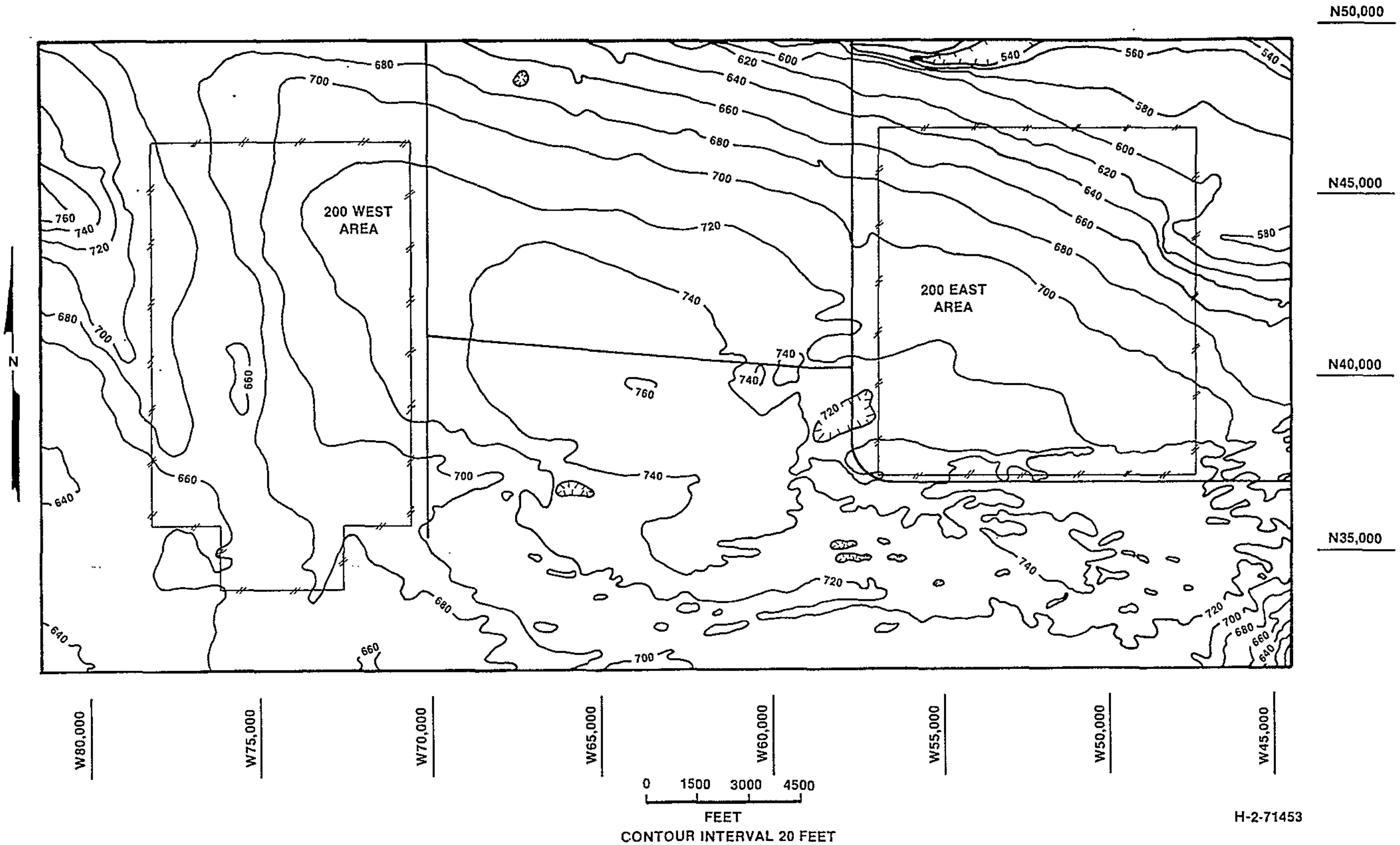

FIGURE B.8

SEPARATION AREAS TOPOGRAPHIC MAP

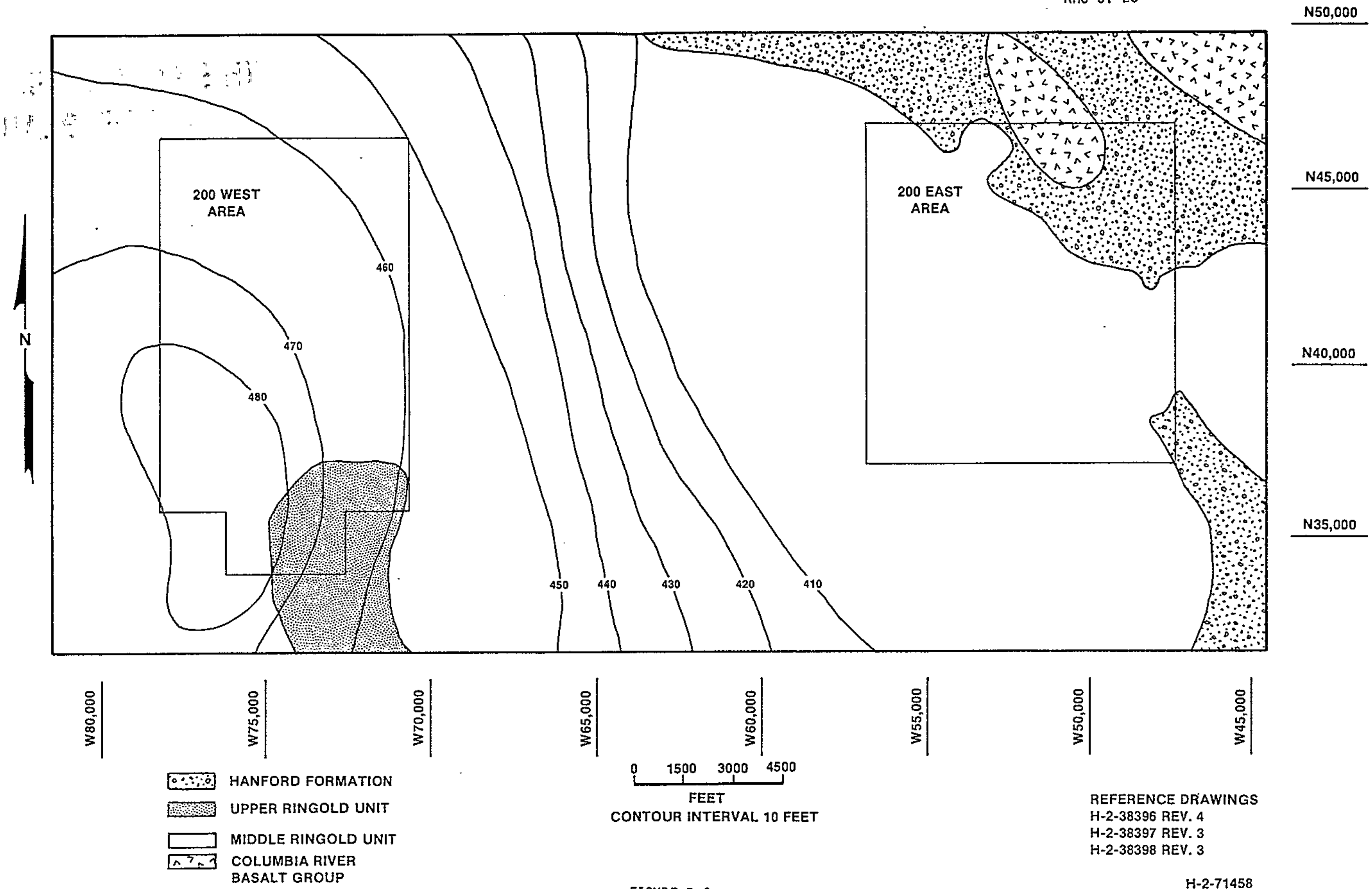

FIGURE B.9

SEPERATION AREAS WATER TABLE MAP

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Appendix C

DRILLING AND SAMPLING METHODS

C.1 INTRODUCTION

Drilling and sampling have been the primary method of collecting geologic and hydrological information to study the ground water, stratigraphy, structure and paleotopography of the geologic units underlying the Hanford Site. The drilling and sampling methods applied depend on the specific needs of the study.

C.2 DRILLING METHODS

The three most commonly used drilling methods for the construction of monitoring, hydrologic investigation and geologic investigation wells are cable-tool percussion drilling, rotary drilling and diamond wire line drilling.

C.2.1 Cable-Tool Percussion Drilling

The cable-tool percussion drilling method has been used to drill over 90 percent of the wells in the Separation Areas. This drilling method is conducted by regularly lifting and dropping a string of heavy drilling tools in the well (Figure C.1). The tools are connected to a left-lay drill line and are dropped in the well. The weight of the tools forces the drill bit into the sediments with a slight rotating action from the drill line. Three basic drilling techniques are used for drilling wells using the cable-tool percussion method.

C.2.1.1 Core Barrel

The most commonly used cable-tool technique utilizes a 5-foot long, heavy-walled pipe, termed core barrel, attached to the drill stem or drill jars. The core barrel is driven into the sediments at the bottom of the well and the sediments are removed by striking the barrel with a hammer. This procedure is repeated until the desired depth of the well is reached.

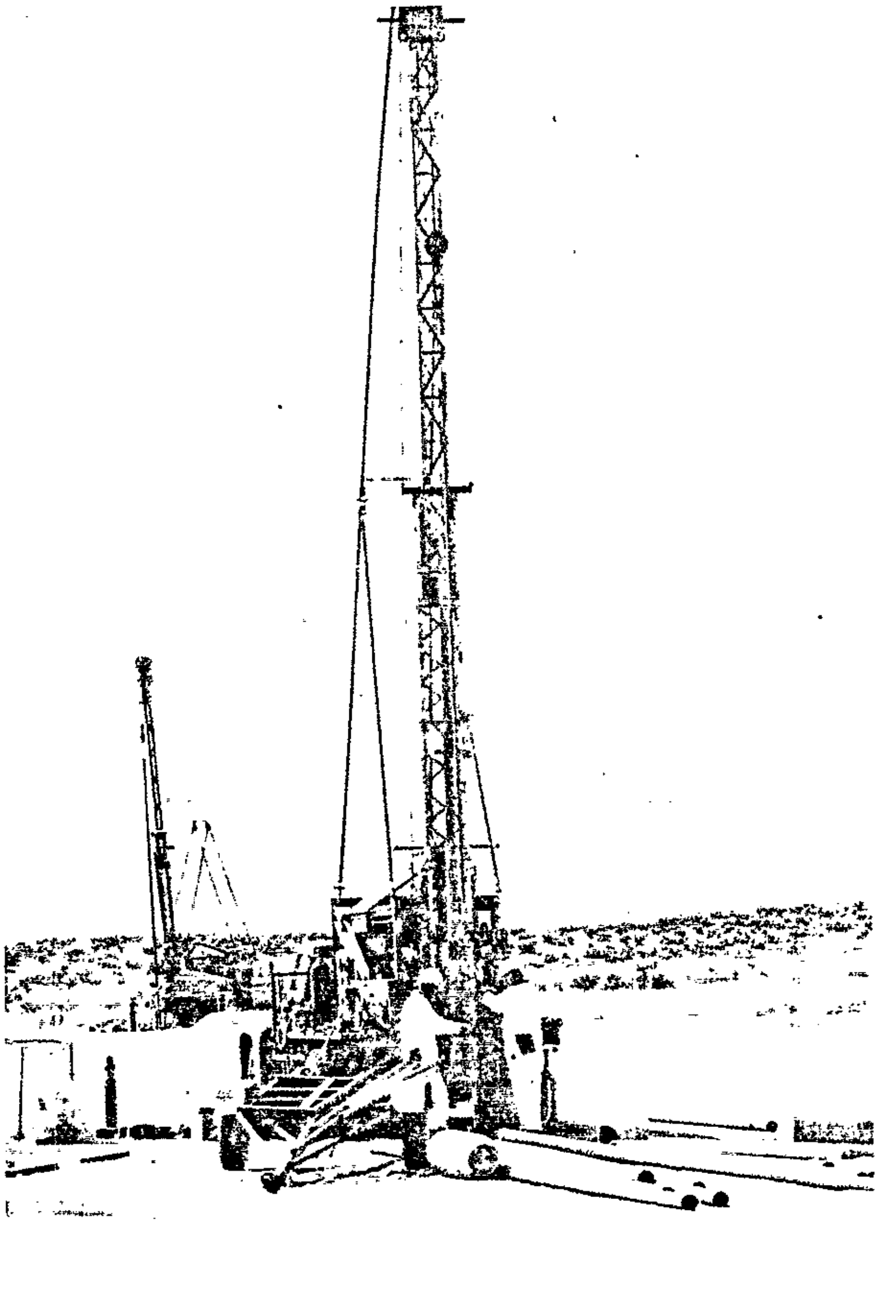

FIGURE C.1

CABLE-TOOL PERCUSSION DRILLING RIG

C.2.1.2 Split-Tube Sampler

The second technique is the split-tube sampler, a specialized core barrel which is used to obtain relatively undisturbed samples. The split-tube sampler consists of an outer split barrel, head, drive shoe and a thin, inner barrel which retains the sediment sample (Figure C.2). The sampler breaks down to the inner barrel which is removed and becomes the sample container. The inner barrel can be cut open to examine and sample the sediments and is replaced each time the sampler is removed from the well. The split-tube sampler is driven into the sediments and retrieved from the well in the same manner as the core barrel.

C.2.1.3 Bit and Bailer

The third cable-tool technique utilizes a bit attached to a drill stem which is regularly lifted and dropped into the well. The reciprocating action of the bit and drill stem, the slight rotating action of the left-lay drill line and necessary water crushes rocks, loosens unconsolidated sediments and forces the bit into the sediments. The mixing of crushed rock, loosened particles and water forms a slurry which is periodically removed from the well by means of a bailer. The procedure is repeated until the desired depth of the well is reached.

C.2.2 Rotary Drilling

The rotary drilling method was used for drilling approximately 30 geologic and hydrologic investigation wells. This method of drilling is conducted by rotating a roller cone bit on the bottom of the well while applying weight and forcing circulation of a drilling fluid out of the bit and up the hole. The purpose of the drilling fluid is to cool the bit and transport cuttings out of the well. The drilling string of tools consists of a bit, drill collars, drill pipe to support the load and to carry the drilling medium, and a kelly on top to rotate the drilling string.

C.2.3 Diamond Wire-Line Core Drilling

The diamond wire-line coring is another method used principally for geological and hydrologic investigation which collects an actual core of the sediments or rock. Ten core wells have been drilled in the

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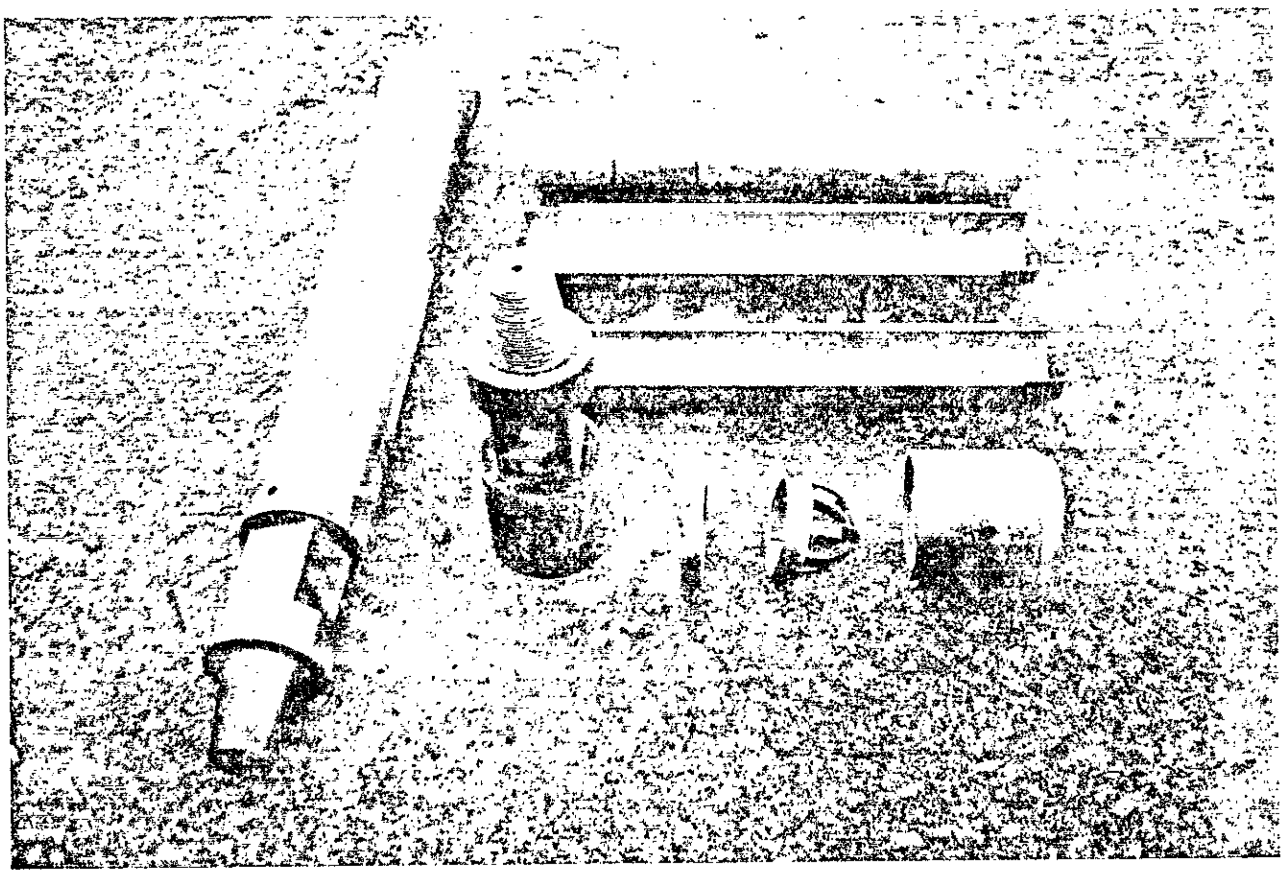

FIGURE C.2

SPLIT TUBE SAMPLER

Separation Areas using the diamond wire-line drilling method. This method uses diamond core bits attached to a core barrel which is connected to drill rods of the same diameter enabling an inner barrel to pass through the drill rods and latch to the core barrel. The inner barrel receives the core as it is cut and is retrieved by a connected wire line. The core is cut by rotating the rods and bit while applying downward pressure on the bit. Drilling mud is circulated down the rods, out of the bit and up the annulus to cool the bit, remove the cuttings and stabilize the hole.

C.3 SAMPLING METHODS

Sediment samples are collected from monitoring wells to provide a permanent record of the sediment types beneath the Hanford Site. Samples are collected at a minimum of 5 foot intervals from the ground surface and at each major change in texture and stored in the Rockwell Sample Repository in 2101-M Building, 200 East Area.

How well the sediment samples collected from the wells represent the actual *in situ* conditions of the sediments depends to a great extent on the type of drilling and sampling method used. The most representative samples are retained in the inner core barrel (diamond wire-line coring) and in the split-tube sampler (cable-tool percussion) which preserve the sediment texture and stratification. Time and cost preclude extensive use of these methods of drilling and sampling.

The core-barrel (cable-tool percussion) method of sampling retains the sediment texture, but the stratification is disturbed when removed from the core barrel. The bailer (cable-tool percussion) and cutting (rotary) method of sampling are the least desirable because crushing or grinding partially destroys the sediment texture and mixing may cross-contaminate sediment types.

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Appendix D

GRANULOMETRIC ANALYSIS OF MONITORING WELL SEDIMENTS

D.1 INTRODUCTION

Disaggregated sediments have been quantitatively analyzed according to a grain-size grouping scheme, termed herein granulometric analysis. The sediments analyzed were collected during the drilling of monitoring wells in the Separation Areas and were utilized to prepare the geologic maps and cross sections given in this report. The relative proportions of different sediment size fractions found in the sediments underlying the Separation Areas are important for the purposes of: (1) defining the relationships of various sediment types, (2) developing approximations of engineering and hydrological properties of sediments, and (3) determining sedimentary genesis.

More than 50,000 sediment samples in the Separation Areas have been analyzed for grain size with disaggregated intermediate diameters ranging from 64 to 0.063 millimeters.[1-14] Size analysis was conducted utilizing a nest of nine screens with wire mesh size openings coinciding to the Wentworth-grade scale divisions.[15] The granulometric data were input to a computer program (ROC) to categorize disaggregated sediment samples into one of nineteen disaggregated sediment classes. Also included in ROC are calcium carbonate data which were determined by a semiquantitative carbon dioxide displacement method.[16]

A discussion of grain-size nomenclature, sediment classification, sieving, calcium carbonate analysis and ROC computer program is included to aid in understanding granulometric analysis.

D.2 GRAIN SIZE NOMENCLATURE

Grain size is one of the most important textural elements of disaggregated sediments. Sediment grain size distributions are controlled by the dynamic processes of sedimentation and are the basis for textural classification schemes. A number of grain-size grouping schemes have been developed which divide the naturally-occurring continuous range of varying grain sizes into specific size groups.

Two types of scales have been used in grain size divisions: linear and geometric. Geometric scales are best suited for sediment description because they give full significance to the smaller size fractions.[17,18] The Wentworth grade scale was used for grain-size nomenclature in the report because: (1) it is the most common grade scale used by geologists, (2) it is a geometric scale, and (3) the grade classes show distinctions in terms of the physical properties involved in grain transportation (Figure D.1).[15,19]

The sediment classification in use at Rockwell Hanford Operations is a triangular diagram, which describes the complete range of disaggregates of gravel, sand, and silt+clay which form the sediments (Figure D.2). Depending on the relative proportions of these three major fractions, each sediment can be categorized into one of nineteen classes. This classification scheme is a modification after Folk which deemphasizes the gravel fraction and places more importance on the sand and the silt+clay fractions.[20]

Two determinations are needed to categorize a disaggregated sediment to a sediment class. First, the gravel fraction is determined as the weight percent of the sediment sample. The percentage of gravel in the sediments is a function of the highest current velocity at the time of deposition. Second, the proportion of sand to silt+clay is determined. This ratio is a function of the winnowing action at the site of deposition. These determinations, percentage gravel and sand-to-silt+clay ratio, are sufficient to categorize a disaggregated sediment sample into one of nineteen sediment classes.[21]

D.3 GRANULOMETRIC ANALYSIS BY SIEVING

Many granulometric techniques are available for grain-size determinations, but no one technique encompasses the entire range of sediment sizes due to the nature of the polydisperse heterogeneous sediment system. For small disaggregated particle sizes, usually less than 0.063 millimeters (230 mesh), the grain size measurements are generally made by a pipette sedimentation technique which measures disaggregated and dispersed grains by settling in water. For large disaggregated particle sizes, greater than 64 millimeters, the intermediate diameters are measured directly. Information on these large

GRAIN SIZE NOMENCLATURE (MODIFIED AFTER C.K. WENTWORTH, 1922)

PARTICLE DESIGNATION			PARTICLE DIAMETER (MM)
GRAVEL		BOULDER	>256
GRAVEL	COBBLE	LARGE	256-128
		SMALL	128-64
GRAVEL	PEBBLE	VERY COARSE	64-32
		COARSE	32-16
		MEDIUM	16-8
		FINE	8-4
		VERY FINE	4-2
	SAND	VERY COARSE	2-1
		COARSE	1-0.5
		MEDIUM	0.5-0.25
		FINE	0.25-0.125
		VERY FINE	0125-0.0625
	SILT & CLAY		<0.0625

FIGURE D.1

GRAIN SIZE NOMENCLATURE
(Modified after C. K. Wentworth, 1922)

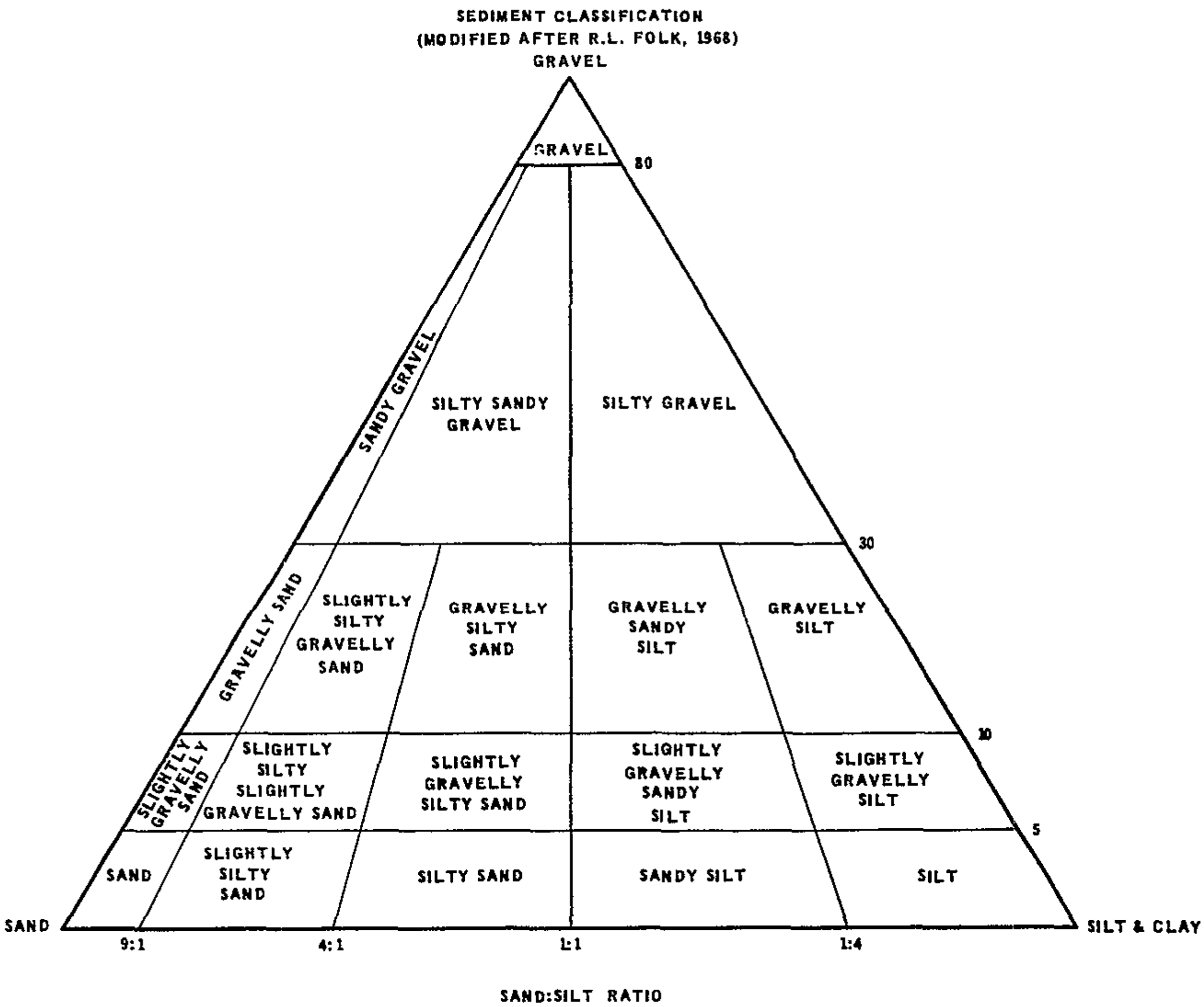

FIGURE D.2

SEDIMENT CLASSIFICATION SCHEME
(Modified after R. L. Folk, 1968)

disaggregated particles is stipulated in the driller's logs. For the range of particle sizes between 0.063 and 4 millimeters (230 and 5 mesh) the granulometric technique most commonly used is sieving.

The granulometric data used in this report were determined by sieving. In the procedure, a weighed aliquot of approximately 150 grams is shaken through a nest of sieves, and the disaggregate retained by each screen is weighed and recorded.

Sieves used for this report are made of brass, 8 inches in diameter, with a wire mesh attached to the base. The wire mesh has known openings which are coincident with the Wentworth grade scale divisions. Sieves with openings range from 0.037 to 4.0 millimeters (5 to 230 mesh) (See Table D-1). The screens are nested with the coarsest mesh[19] on the top descending in coarseness to the finest mesh on the bottom (230).

A RoTap, or similar mechanical shaker, is used to shake the disaggregate in the nest of sieves. The shaking time is optimized at 15 to 25 minutes.[22] This shaking period adequately completes the separation of disaggregated sediments, and avoids extensive mesh wear.[23]

D.4 CALCIUM CARBONATE CONTENT OF SEDIMENT SAMPLES

The calcium carbonate content of sediments is used to aid in the identification of marker horizons for developing stratigraphic maps and geologic cross sections, and to determine the sorption properties of calcareous sediments. Calcium carbonate determinations are made by reacting sediment carbonates with acid to stoichiometrically produce carbon dioxide and measure the volume of carbon dioxide gas produced.[16]

D.5 ROC COMPUTER PROGRAM

A data base management system, termed ROC, was developed to handle and process raw granulometric and calcium carbonate data. The ROC system converts raw sediment data into a usable format for preparation of geologic maps and cross sections, and represents an inventory of all sediment samples that have been analyzed for grain size and calcium carbonate content by Rockwell Hanford Operations.

TABLE D.1

SCREEN SIZES AND THEIR
RESPECTIVE WENTWORTH GRADE SCALE SIZES

U.S. Standard Sieve Mesh #	Sieve Opening Size: Inches	Sieve Opening Size: Millimeters	Grain Size Nomenclature (Wentworth Grade Scale)
			Larger Than Very Fine Pebbles
5	1.6×10^{-1}	4	
			Very Fine Pebbles
10	7.9×10^{-2}	2	
			Very Coarse Sand
18	3.9×10^{-2}	1	
			Coarse Sand
35	2.0×10^{-2}	0.5	
			Medium Sand
60	9.8×10^{-3}	0.25	
			Fine Sand
120	4.9×10^{-3}	0.125	
			Very Fine Sand
230	2.4×10^{-3}	0.063	
			Coarse Silt
270	1.5×10^{-3}	0.037	
			Medium Silt to Clay

The ROC computer program lists the well number using the Hanford well numbering system[24] the date of the computer run, the depth the sample was collected, and for each depth the following information: (1) the calcium carbonate content determined by the semiquantitative displacement method; (2) the drilling method (C-core barrel or split-tube sampler H-hardtool (bit and bailer); (3) the percentages of silt+clay (mud), sand, and gravel; (4) the sediment class calculated by the computer based on the percentage of gravel and the sand-to-silt+clay ratio; (5) the weight percent for each of nine sediment size ranges; and (6) the cumulative weight percent of the sediment size ranges (Table D.2).

TABLE D.2

ROC COMPUTER PRINT OUT - WELL 299-W22-2

DATE 110978 **** REPORT ON WELL 0299-W22-002 ****

DEPTH	%CACO3	OH	%MUD	%SAND	%GRAV	CLASS	FINE PEB	VFINE PEB	VERY COARS	COARS	MED	FINE	VERY FINE	SILT	PAN
85	1.7	H	16.5	83.3	.2	(M)S	0.0	.2	3.0	12.0	15.9	26.7	25.7	8.2	8.2
							0.0	.2	3.2	15.2	31.1	57.8	83.5	91.8	100.0
90	1.7	H	17.2	82.5	.3	(M)S	0.0	.3	2.0	7.7	11.8	33.7	27.3	8.9	8.4
							0.0	.3	2.2	9.9	21.8	55.5	82.8	91.6	100.0
95	1.7	H	15.1	84.4	.5	(M)S	0.0	.5	4.0	16.8	18.4	24.6	20.7	7.3	7.8
							0.0	.5	4.5	21.3	39.7	64.3	84.9	92.2	100.0
100	1.6	H	18.6	81.3	.1	(M)S	0.0	.1	1.0	7.8	21.0	29.9	21.6	8.5	10.1
							0.0	.1	1.1	9.0	30.0	59.9	81.4	89.9	100.0
105	1.5	H	18.4	81.4	.1	(M)S	0.0	.1	.8	6.5	17.8	30.9	25.4	8.7	9.7
							0.0	.1	.9	7.4	25.2	56.1	81.6	90.3	100.0
110	1.5	H	17.8	81.9	.2	(M)S	0.0	.2	.7	5.5	19.7	32.3	23.7	9.0	8.9
							0.0	.2	.9	6.4	26.2	58.5	82.2	91.1	100.0
115	1.8	H	29.1	70.9	0.0	MS	0.0	0.0	.3	3.1	16.1	27.3	24.1	13.7	15.3
							0.0	0.0	.3	3.4	19.5	46.8	70.9	84.7	100.0
120	1.9	H	21.3	78.6	.1	MS	0.0	.1	.2	2.1	14.1	35.0	27.2	10.9	10.4
							0.0	.1	.3	2.4	16.5	51.5	78.7	89.6	100.0
125	2.1	H	27.1	72.7	.2	MS	.2	0.0	.1	1.2	10.0	29.2	32.1	14.0	13.1
							.2	.2	.3	1.5	11.5	40.8	72.9	86.9	100.0
130	2.5	H	48.1	51.8	.1	MS	0.0	.1	.1	.7	7.0	16.2	27.8	21.7	26.5
							0.0	.1	.1	.9	7.8	24.0	51.9	73.5	100.0
135	2.2	H	51.3	48.7	0.0	SM	0.0	0.0	.1	.2	3.6	14.7	30.1	25.2	26.1
							0.0	0.0	.1	.3	3.9	18.6	48.7	73.9	100.0
140	2.5	H	63.5	36.5	0.0	SM	0.0	0.0	.1	.4	5.3	9.3	21.4	33.8	29.8
							0.0	0.0	.1	.5	5.8	15.0	36.5	70.2	100.0
145	5.6	H	33.3	52.8	13.9	GMS	7.3	6.7	5.0	7.4	13.5	10.3	16.6	18.3	15.0
							7.3	13.9	19.0	26.4	39.9	50.1	66.7	85.0	100.0
150	1.9	H	18.3	61.4	20.3	GMS	10.7	9.5	9.9	16.0	14.6	10.5	10.4	8.1	10.2
							10.7	20.3	30.2	46.1	60.7	71.2	81.7	89.8	100.0
152	.1	H	5.6	94.3	.1	S	0.0	.1	5.4	37.2	34.7	12.6	4.4	2.3	3.3
							0.0	.1	5.5	42.7	77.4	90.0	94.4	96.7	100.0
154	.2	H	7.9	83.6	8.5	(G)S	.7	7.7	15.9	34.3	20.5	8.6	4.4	2.9	5.0
							.7	8.5	24.3	58.6	79.1	87.7	92.1	95.0	100.0

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Appendix E

MINERALOGICAL ANALYSIS

E.1 INTRODUCTION

Mineralogical analyses of selected sediments underlying the Separation Areas were conducted as part of sediment-waste reaction studies to provide more accurate predictive capability on the mobility of radionuclides, and to facilitate the determination of the spacial distribution of radionuclides beneath waste management facilities. Another purpose for the mineralogical analyses was to compare the composition of Hanford and Ringold sediments to determine if mineral compostion might be used to differentiate these two formations. The mineralogical analyses were designed to emphasize study of the finer sediment fractions which contain the higher cation exchange minerals.

All mineralogical analyses were performed by Ames, Battelle, Pacific Northwest Laboratory. The analytical data presented in this appendix are particle size analyses, X-ray diffraction, electron microprobe, and basalt content. The data are shown in Tables E.1, E.2, and E.3, and are separated into the Ringold Formation, early "Palouse" soil, and Hanford Formation. The data are presented in numerical well order for each of the sedimentary units.

E.2 PARTICLE SIZE ANALYSIS

Particle size separation was accomplished by sieving and elutriation. Each sample was put into three nested sieves, using U.S. Standard mesh numbers 10, 40, and 200 (Table E.4), and shaken by a mechanical shaker. Sieving separated the gravel and two sand fractions from the silt and clay fraction.

The silt and clay fraction along with some very fine sand (<200 mesh) was further size fractioned by elutriation. Using the relationship of the settling velocity of particles to their diameter, separations were made and percents calculated for 50-74μ, 5-50μ and <2μ. The results of the particle size analyses are given in Table E.1. All data are expressed as percent of total.

E.3 X-RAY DIFFRACTION

X-ray diffraction methods measure the spacing between the structural framework units of the minerals present. The X-ray diffraction tracings were used to estimate the relative abundance of mineral constituents of the total (as received) sample and various size fractions.

The mineral constituents are listed in order of relative abundance in each size range. To determine the relative abundance in the total sample, it is necessary to compare the X-ray diffraction data with the particle size distribution. The X-ray diffraction and particle size analysis for selected sediment samples are shown in Table E.1.

E.4 MICROPROBE ANALYSIS

The mineralogical composition of the sand and/or finer sediment fractions were determined from elemental distributions obtained on the electron microprobe. Minerals were identified by referring to their elemental contents as shown in X-ray emission photomicrographs for silican, aluminum, iron, calcium, magnesium, titanium, potassium and sodium (Figure E.1 and E.2). Table E.2 gives the mineralogical composition of the non-basaltic portion of selected size ranges of each sediment sample. The size range percentage is given for each sample.

E.5 BASALT CONTENT

The basalt content of each sample was determined for various size fractions of each sample. The basalt in fractions >10 mesh (Table E.3) was hand separated and weighed. In fractions <10 mesh, the basalt fragments were identified in optical photomicrographs and the area of basalt fragments was used to determine the weight of basalt.

The basalt content of the sediments is given in Table E.3. If a size range contained no sediment sample, "ns" appears on the table. If the percent basalt was not determined, a "-" appears on the table. Percent basalt for miscellaneous size ranges is shown in the last column with the size range and percent basalt given.

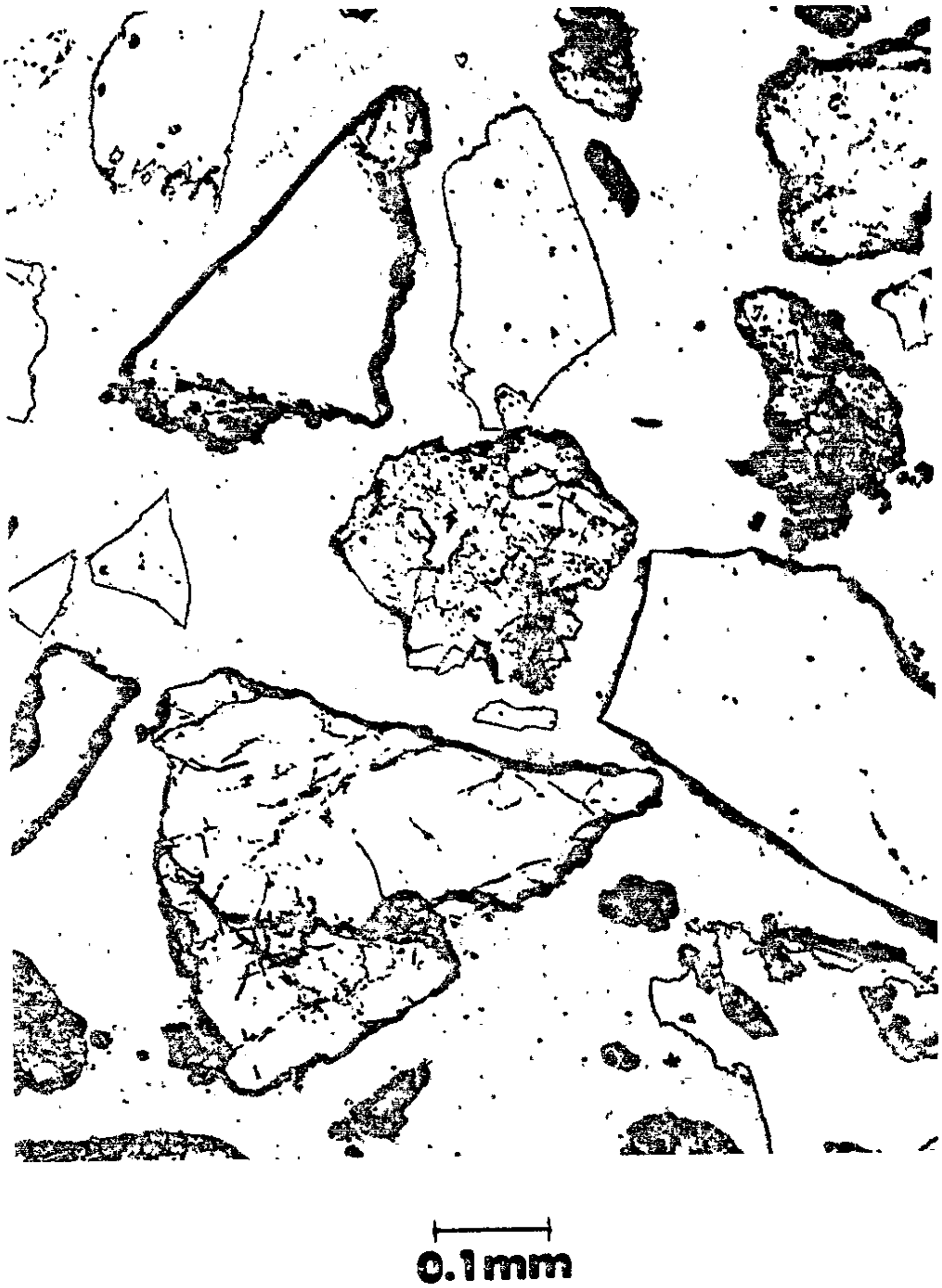

FIGURE E.1

OPTICAL PHOTOMICROGRAPH

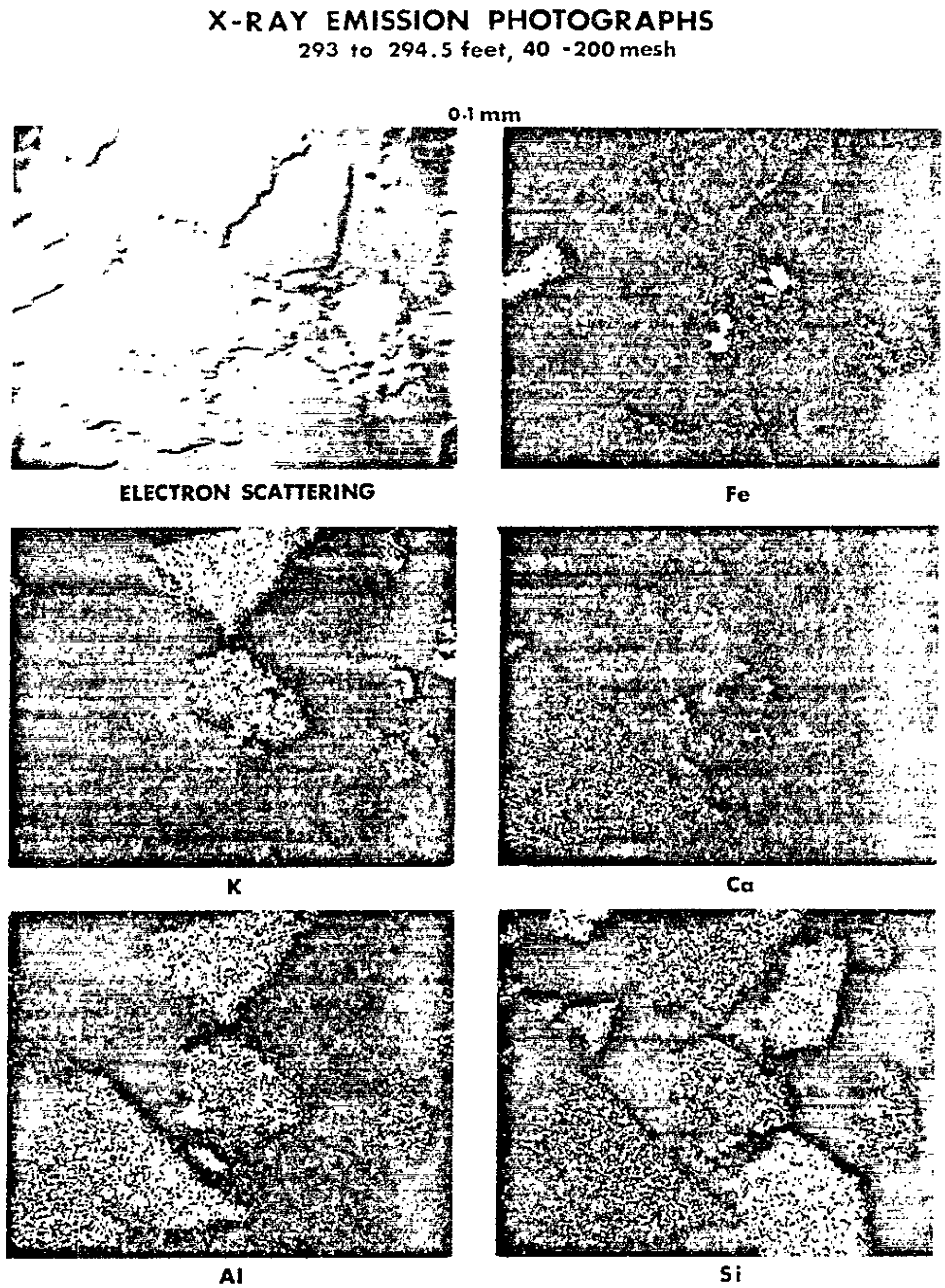

FIGURE E.2

X-RAY EMISSION PHOTOMICROGRAPHS

TABLE E.1

PARTICLE SIZE AND X-RAY DIFFRACTION DATA

			PARTICLE SIZE ANALYSIS						MINERALOGICAL ANALYSIS				
		SAMPLE	>2mm	2-0.42mm	420-74μ	<74μ	<2μ		AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
RINGOLD FORMATION	BASAL RINGOLD UNIT	W11-26, 427'	0.0	0.0	39.9	60.1	17.2		Quartz Feldspar	Smectite Mica Chlorite Quartz Feldspar	Quartz Mica Feldspar	Quartz Feldspar Mica	
		W11-26, 490'	88.3	3.1	5.4	3.1	0.6		Quartz Feldspar	Smectite	Smectite Quartz Feldspar Mica	Smectite Quartz Feldspar Mica	
		W19-10, 519'	71.2	14.1	12.9	1.8	0.4		Quartz Feldspar	Smectite Quartz Feldspar	Smectite Quartz Feldspar	Quartz Feldspar Smectite	
		E19-1, 426'	0.4	0.2	46.5	53.0	7.1			Smectite Chlorite			Quartz Feldspar Chlorite Mica
		E19-1, 450'	79.2	9.7	10.0	1.1	0.5		Quartz Feldspar Mica	Smectite		Quartz Feldspar Mica	
		E19-1, 488'	90.2	3.0	5.9	0.9	0.5		Quartz Feldspar Mica	Smectite Mica Chlorite		Quartz Feldspar Mica Smectite Chlorite	
		E19-1, 511'	85.3	10.0	3.9	0.8	0.4		Quartz Feldspar Mica	Smectite		Quartz Feldspar Mica Chlorite Smectite	

TABLE E.1

(CONTINUED)

			PARTICLE SIZE ANALYSIS					MINERALOGICAL ANALYSIS				
		SAMPLE	>2mm	2-0.42mm	420-74μ	<74μ	<2μ	AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
RINGOLD FORMATION	LOWER RINGOLD UNIT	W19-10, 460.5'	54.5	0.4	26.8	18.4	1.6		Mica Smectite Chlorite Quartz			Quartz Feldspar Mica Smectite
		W19-10, 484.5'	0.0	0.0	88.8	11.2	0.3		Mica Chlorite Smectite Quartz			Quartz Feldspar Mica Chlorite
		E19-1, 385'	0.0	0.0	6.7	93.3	1.9	Quartz Mica Feldspar	Mica Chlorite Smectite		Quartz Mica Chlorite Feldspar	
	MIDDLE RINGOLD UNIT	W11-26, 203'	86.7	3.0	9.7	0.5	0.1					Quartz Feldspar Smectite
		W11-26, 293'	67.2	14.9	16.4	1.7	0.4					Quartz Feldspar Opal Calcite
		W11-26, 390'	76.1	2.4	18.3	3.2	0.6	Quartz Feldspar	Quartz Feldspar Smectite	Quartz Calcite Feldspar	Quartz Calcite Feldspar	
		W19-10, 181'	90.1	4.0	2.0	3.9	0.8	Quartz Feldspar Mica	Smectite Calcite	Quartz Calcite Smectite Felspar Chlorite	Quartz Calcite Feldspar	

TABLE E.1

(CONTINUED)

RINGOLD FORMATION — MIDDLE RINGOLD UNIT

PARTICLE SIZE ANALYSIS						MINERALOGICAL ANALYSIS				
SAMPLE	>2mm	2-0.42mm	420-74μ	$<74\mu$	$<2\mu$	AS RECEIVED	$<2\mu$	2-5μ	5-50μ	$<74\mu$
W19-10, 234'	89.9	2.5	5.0	2.6	0.5	Quartz Feldspar	Smectite	Smectite Quartz	Quartz Feldspar Smectite	
W19-10, 275'	0.0	1.8	74.3	23.9	4.0	Quartz Mica Felspar	Smectite Quartz Mica Chlorite Feldspar	Smectite Quartz Mica Chlorite Feldspar	Quartz Mica Smectite Chlorite Feldspar	
W19-10, 285'	0.0	5.0	91.5	3.5	0.7	Quartz Feldspar	Smectite Quartz Chlorite Mica Felspar	Smectite Quartz Mica Feldspar	Smectite Quartz Feldspar	
W19-10, 365'	68.7	3.1	23.7	4.5	0.9	Quartz Calcite	Smectite Calcite Quartz Feldspar	Smectite Calcite Quartz Mica Feldspar	Quartz Smectite Calcite Mica	
E27-6, 293'	80.6	11.4	3.6	4.4	0.2	Quartz Feldspar Mica			Quartz Feldspar Calcite Mica	
E27-6, 310'	100.0	0.0	0.0	0.0	0.0					
E27-6, 328'	100.0	0.0	0.0	0.0	0.0					

TABLE E.1

(CONTINUED)

	SAMPLE	PARTICLE SIZE ANALYSIS >2mm	2-0.42mm	420-74μ	<74μ	<2μ	MINERALOGICAL ANALYSIS AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
RINGOLD FORMATION – UPPER RINGOLD UNIT	W11-26, 138'	0.0	0.1	7.0	92.9	32.5	Quartz Feldspar	Quartz Mica Smectite	Quartz Feldspar Mica	Quartz Feldspar Mica	
EARLY "PALOUSE" SOIL	S[1]	0.5	2.5	31.0	66.0	0.0	Quartz Feldspar	Smectite Mica Chlorite Quartz	Quartz Feldspar Mica	Quartz Feldspar Mica	
EARLY "PALOUSE" SOIL	T[2]	9.8	11.0	23.9	55.3	0.0	Quartz Feldspar Mica	Smectite Mica Chlorite Quartz	Quartz Mica Feldspar	Quartz Feldspar Mica	
EARLY "PALOUSE" SOIL	W11-26.110'	0.7	2.3	14.1	82.9	0.0	Quartz Feldspar	Chlorite Smectite Quartz Feldspar	Quartz Feldspar	Quartz Feldspar	
HANFORD FORMATION	A[3]	7.3	9.2	41.3	42.2	0.0	Quartz Feldspar	Chlorite Smectite Mica Quartz Feldspar	Quartz Felspar Mica Calcite	Quartz Feldspar Mica Calcite	
HANFORD FORMATION	SY[4], 25'	0.0	4.0	78.2	17.8	3.5	Feldspar Quartz	Smectite Mica Chlorite Quartz	Quartz Mica	Quartz Feldspar Mica	
HANFORD FORMATION	SY[4], 30'	1.1	58.3	37.0	3.6	0.7	Feldspar Quartz	Smectite	Quartz Chlorite Mica	Feldspar Quartz	

1 Composite sample from 241-S Tank Farm
2 Composite sample from 241-T Tank Farm
3 Composite sample from 241-A Tank Farm
4 Composite sample from 241-SY Tank Farm excavation

9 2 1 2 4 6 6 1 1 1 3

TABLE E.1

(CONTINUED)

HANFORD FORMATION

	PARTICLE SIZE ANALYSIS					MINERALOGICAL ANALYSIS				
SAMPLE	>2mm	2-0.42mm	420-74μ	<74μ	<2μ	AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
W10-148, 80'	5.7	53.2	33.1	8.0	1.5	Quartz Feldspar Mica	Mica Smectite Feldspar	Mica Smectite Quartz Chlorite Calcite	Quartz Feldspar Mica Chlorite	
W11-10, 90'	16.2	58.6	21.3	4.0	0.4		Smectite Chlorite Mica Quartz			Feldspar Quartz Mica Chlorite
W14-8, 100'	3.3	59.2	30.8	6.7	0.3		Quartz Mica Chlorite			Quartz Feldspar Mica Chlorite
W15-86, 56'	9.9	41.0	34.3	14.8	2.0		Smectite Mica Chlorite Quartz			Quartz Feldspar Mica Chlorite
W15-86, 82'	0.8	20.9	60.8	17.5	1.4		Smectite Mica Chlorite Quartz			Quartz Feldspar Mica Chlorite
W15-86, 110'	1.0	21.8	54.6	22.7	1.5		Smectite Chlorite Quartz Mica Feldspar			Quartz Feldspar Mica Chlorite
W23-52, 100'	0.7	10.6	58.3	30.4	6.5	Quartz Feldspar	Mica Quartz Chlorite Smectite Feldspar	Mica Quartz Smectite Chlorite Feldspar	Quartz Mica Feldspar Chlorite	

TABLE E.1

(CONTINUED)

	PARTICLE SIZE ANALYSIS						MINERALOGICAL ANALYSIS				
	SAMPLE	>2mm	2-0.42mm	420-74µ	<74µ	<2µ	AS RECEIVED	<2µ	2-5µ	5-50µ	<74µ
HANFORD FORMATION	W23-72, 100'	0.0	4.5	73.1	22.4	4.5	Quartz Feldspar	Quartz Mica Chlorite Smectite Feldspar	Quartz Mica Chlorite Smectite Feldspar	Quartz Feldspar Mica	
	W23-108, 105'	0.0	7.4	63.2	29.4	6.0	Quartz Mica Feldspar	Mica Smectite Chlorite	Smectite Mica Quartz Chlorite	Quartz Mica Feldspar	
	E13-5, 185'	0.8	12.4	73.3	14.2	1.2		Quartz Mica Chlorite Feldspar			Quartz Feldspar Mica Chlorite
	E13-8, 70'	0.7	38.6	45.3	15.4	1.8		Mica Chlorite Quartz Feldspar			Quartz Feldspar Mica Chlorite
	E16-1, 60'	0.2	70.4	25.0	4.5	0.5		Mica Chlorite Smectite			Feldspar Quartz Mica Chlorite
	E16-1, 125'	57.7	12.7	23.6	6.0	0.3		Mica Chlorite			Quartz Feldspar Mica Chlorite

TABLE E.1

(CONTINUED)

	PARTICLE SIZE ANALYSIS						MINERALOGICAL ANALYSIS				
	SAMPLE	>2mm	2-0.42mm	420-74μ	<74μ	<2μ	AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
HANFORD FORMATION	E24-9, 50'	2.6	58.9	26.2	12.3	1.0		Chlorite Quartz Mica Feldspar			Quartz Feldspar Chlorite Mica
HANFORD FORMATION	E24-9, 90'	0.2	25.8	60.1	13.9	1.0		Smectite Quartz Chlorite Mica			Quartz Feldspar Mica Chlorite
HANFORD FORMATION	E25-2, 10'	0.1	6.2	65.8	27.9	2.3		Smectite Mica Quartz Chlorite Feldspar			Feldspar Quartz Mica Chlorite
HANFORD FORMATION	E25-15, 100'	0.5	49.3	40.8	9.4	0.0	Quartz Feldspar	Mica Smectite Quartz Chlorite Feldspar	Quartz Mica Smectite Chlorite Feldspar	Quartz Mica Chlorite Feldspar	
HANFORD FORMATION	E27-6, 198'	9.7	73.0	11.2	6.1	1.2	Quartz Feldspar Mica	Smectite Mica		Quartz Feldspar Mica Chlorite	
HANFORD FORMATION	E27-6, 264'	0.0	0.0	8.3	91.7	33.7	Quartz Feldspar Chlorite Mica	Chlorite Mica Smectite		Quartz Feldspar Chlorite Mica Smectite	
HANFORD FORMATION	E28-22, 207'	1.1	73.6	22.1	3.2	0.5	Quartz Feldspar Mica	Smectite Mica Chlorite		Quartz Feldspar Mica Chlorite Smectite	

TABLE E.1

(CONTINUED)

	PARTICLE SIZE ANALYSIS						MINERALOGICAL ANALYSIS				
	SAMPLE	>2mm	2-0.42mm	420-74μ	< 74μ	<2μ	AS RECEIVED	<2μ	2-5μ	5-50μ	<74μ
HANFORD FORMATION	E33-201, 50'	4.1	78.3	12.8	4.8	0.0	Quartz Feldspar	Smectite Mica Chlorite Quartz Feldspar	Smectite Mica Chlorite Quartz Feldspar	Quartz Feldspar Mica Chlorite	
	E33-244, 70'	0.3	67.8	20.6	10.8	0.0	Quartz Feldspar	Quartz Mica Chlorite Feldspar Smectite	Quartz Mica Chlorite Smectite Feldspar	Quartz Mica Feldspar Chlorite	

TABLE 3.2

MINGERALOGICAL COMPOSITION - MICROPROBE DATA

RINGOLD FORMATION

	Basal Ringold Unit							Lower Ringold Unit		
Well	W11-26	W11-26	W19-10	E19-1	E19-1	E19-1	E19-1	W19-10	W19-10	E19-1
Depth in Ft	427	490	519	426	450	488	511	460.5	484.5	385
Weight %	100.0	5.4	27.0	46-61	10.0	5.9	3.9	27.17	88.84	6.7
Mesh Size		40-200	10-200	10-200	40-200	40-200	40-200	10-200	10-200	40-200
MINERAL										
Albite	—	—	—	—	—	—	—	—	—	—
Amphibole	—	10.3	0.9	16.8	6.2	—	7.7	—	10.4P	4.9
Apatite	—	—	—	—	—	—	—	—	—	—
Calcite	—	3.8	—	0.9	—	—	—	1.0	0.2	—
Chlorite	—	—	—	—	—	—	—	—	—	30.1
Diopside	—	—	—	—	—	—	—	—	—	—
Epidote	3.3	—	2.1	—	—	—	—	—	—	—
Garnet	—	—	—	—	—	—	—	—	1.9	—
Ilmenite	—	—	1.7	—	—	4.0	1.6	—	1.4	—
Magnetite	2.5	7.9	0.4	4.2	5.1	—	—	—	1.3	—
Mica	—	—	3.4	6.6	8.6	2.8	—	—	7.9	15.0
Microcline	38.0	12.0	22.0	8.5	7.9	37.1	25.1	10.6	21.5	4.3
Nontronite	—	—	3.6	—	—	—	—	—	—	—
Olivine	—	—	—	—	—	—	—	—	—	—
Plagioclase	3.0	20.0	11.6	10.1	9.6	8.5	7.7	17.6	7.8	—
Pyrite	—	—	—	20.8	—	—	—	—	—	—
Pyroxene	—	—	—	—	—	—	—	—	—	—
Quartz	51.9	43.5	54.4	32.3	62.6	44.8	57.9	70.9	47.8	45.6
Rutile	1.3	2.5	—	—	—	—	—	—	—	—
Sphene	—	—	—	—	—	2.8	—	—	—	—
Zircon	—	—	—	—	—	—	—	—	—	—
*Glass	—	—	—	—	—	—	—	—	—	—

P Pyroxene included in amphibole data
* Glass is not a mineral but is included in this data

9 2 1 2 4 6 6 1 1 2 3

TABLE E.2

(CONTINUED)

	RINGOLD FORMATION									
	Middle Ringold Unit									Upper Ringold Unit
Well	W11-26	W11-26	W11-26	W19-10	W19-10	W19-10	W19-10	W19-10	E27-6	W11-26
Depth in Ft	203	293	390	181	234	275	285	365	293	138
Weight %	9.7	16.4	18.3	5.9	7.6	100.0	100.0	23.7	3.6	92.9
Mesh Size	40-200	40-200	40-200	<40	<40			40-200	40-200	200
MINERAL										
Albite	—	—	—	3.3	—	—	—	—	—	—
Amphibole	1.8	4.0	—	15.6	1.6	—	4.6	7.6	—	6.7
Apatite	—	4.4	—	0.1	1.3	—	—	—	—	3.4
Calcite	2.2	—	12.3	13.1	1.3	—	—	23.5	—	8.0
Chlorite	—	—	—	—	—	—	—	—	—	—
Diopside	—	—	—	—	—	—	—	—	—	—
Epidote	7.0	—	—	—	0.5	1.8	—	4.2	—	3.4
Garnet	3.5	—	—	—	—	—	—	—	—	—
Ilmenite	1.3	5.5	—	3.5	5.7	—	8.8	1.3	—	1.4
Magnetite	7.8	4.9	2.7	11.6	4.1	2.3	—	7.2	8.4	4.0
Mica	—	—	—	0.9	6.6	21.3	1.8	—	—	—
Microcline	23.2	26.8	28.8	10.2	23.5	20.1	21.1	8.4	12.0	21.8
Nontronite	—	—	—	—	3.1	—	—	—	—	—
Olivine	—	—	—	—	—	—	—	—	—	—
Plagioclase	20.1	19.7	9.2	18.3	14.4	1.1	22.8	13.8	10.8	10.6
Pyrite	—	—	—	—	—	—	—	—	—	—
Pyroxene	—	—	—	3.4	0.8	—	—	—	—	—
Quartz	33.0	34.8	47.0	19.6	37.1	53.4	40.8	34.0	68.9	40.5
Rutile	—	—	—	0.5	—	—	—	—	—	—
Sphene	—	—	—	—	—	—	—	—	—	—
Zircon	—	—	—	—	—	—	—	—	—	—
*Glass	—	—	—	—	—	—	—	—	—	—

* Glass is not a mineral but is included in this data

TABLE E.2

(CONTINUED)

	EARLY "PALOUSE" SOIL		
Well	W11-26	S[1]	T[2]
Depth in Ft	110		
Weight %	100.0	100.0	100.0
Mesh Size			
MINERAL			
Albite	0.4	—	—
Amphibole	7.9	7.9	10.0
Apatite	—	0.7	2.6
Calcite	8.0	8.2	8.8
Chlorite	—	—	—
Diopside	—	—	—
Epidote	—	—	—
Garnet	—	—	1.9
Ilmenite	1.7	—	3.5
Magnetite	16.1	5.7	8.2
Mica	2.9	12.5	1.3
Microcline	17.8	15.0	16.1
Nontronite	—	—	—
Olivine	—	—	—
Plagioclase	15.1	18.2	17.8
Pyrite	—	—	—
Pyroxene	—	—	—
Quartz	27.9	29.4	25.3
Rutile	1.3	2.4	3.6
Sphene	0.9	—	—
Zircon	—	—	—
*Glass	—	—	1.0

1 Composite sample from 241-S Tank Farm
2 Composite sample from 241-T Tank Farm
* Glass is not a mineral, but is included in this data

TABLE E.2

(CONTINUED)

HANFORD FORMATION

Well	A^3	SY^4	SY^4	W10-148	W10-148	W10-148	W11-10	W14-8	W23-52	W23-72
Depth in Ft		25	30	80	80	80	90	100	100	100
Weight %	100.0	<17.8	<3.6	53.1	33.1	86.3	79.82	9.04	100.0	100.0
Mesh Size		200-270	200-27	10-40	40-200	10-200	10-200	10-200		
MINERAL										
Albite	—	—	—	—	—	—	—	—	—	6.8
Amphibole	12.0	—	—	5.5	0.9	3.7	4.2^P	2.1^P	—	13.3
Apatite	—	0.7	0.9	0.2	0.5	0.3	—	—	3.8	—
Calcite	6.4	1.3	2.9	—	1.8	0.7	3.1	0.8	—	2.5
Chlorite	—	—	—	—	—	—	6.4	—	—	—
Diopside	—	—	—	—	—	—	—	—	—	—
Epidote	—	—	—	—	10.3	4.0	—	—	—	—
Garnet	—	1.4	—	—	—	—	—	—	—	—
Ilmenite	—	2.0	1.0	—	—	—	—	3.6	3.1	3.3
Magnetite	14.2	5.2	2.7	—	2.9	1.1	3.4	4.6	11.1	4.7
Mica	2.6	5.1	6.3	1.5	13.1	5.9	4.4	—	—	0.6
Microcline	14.6	8.7	3.6	21.6	13.0	18.3	10.6	16.8	16.1	15.4
Nontronite	—	—	—	0.6	—	0.4	—	—	—	—
Olivine	—	0.7	0.7	—	—	—	—	—	—	—
Plagioclase	17.1	19.4	31.4	15.1	24.7	18.8	5.1	18.0	24.6	30.2
Pyrite	—	—	—	—	—	—	—	—	—	—
Pyroxene	—	22.9	16.8	8.6	0.4	5.5	—	—	—	2.8
Quartz	31.6	18.0	20.5	46.9	31.5	41.0	62.9	54.1	41.2	20.2
Rutile	1.4	—	—	—	—	—	—	—	—	—
Sphene	—	—	1.0	—	1.0	0.4	—	—	—	—
Zircon	—	—	—	—	—	—	—	—	—	—
*Glass	—	14.7	11.4	—	—	—	—	—	—	—

3 Composite sample from 241-A Tank Farm
4 Composite sample from 241-SY Tank Farm excavation
P Pyroxene included in amphibole data
* Glass is not a mineral but is included in this data

TABLE E.2

(CONTINUED)

HANFORD FORMATION (Continued)

Well	W23-108	E13-5	E13-8	E16-1	E16-1	E25-15	E27-6	E27-6	E28-22	E33-201	E33-244
Depth in Ft	105	185	70	60	125	100	198	264	207	50	70
Weight %	100.0	85.7	83.9	95.34	36.27	100.0	11.2	8.3	22.1	78.2	100
Mesh Size		10-200	10-200	10-200	10-200		40-200	40-200	40-200	10-40	
MINERAL											
Albite	2.7	—	—	—	—	2.7	—	—	—	—	—
Amphibole	17.9	11.9P	10.7	36.3P	3.1P	17.9	14.7	12.4	10.1	0.1	5.5
Apatite	1.1	—	4.1	—	—	1.1	—	—	1.1	0.1	0.4
Calcite	2.3	2.9	—	—	—	2.3	—	2.1	2.6	0.2	—
Chlorite	—	11.1	11.7	—	11.4	—	—	14.5	—	—	—
Diopside	—	—	—	—	2.7	—	—	—	—	—	—
Epidote	—	—	—	—	—	—	—	—	—	1.3	—
Garnet	—	—	—	—	—	—	—	—	—	—	—
Ilmenite	1.9	10.1	6.0	2.7	—	1.9	—	—	—	2.4	5.2
Magnetite	1.9	5.1	15.0	2.8	7.7	1.9	—	2.1	—	4.5	7.6
Mica	0.1	9.4	11.3	—	4.1	0.1B	7.4	10.3	—	1.7	—
Microcline	11.7	10.1	6.6	1.8	6.5	11.7	19.6	9.0	30.1	19.2	27.1
Nontronite	—	—	—	—	—	—	—	—	—	—	—
Olivine	—	—	—	—	—	—	—	—	—	—	—
Plagioclase	22.2	9.7	—	34.0	14.0	22.2	23.5	8.3	12.2	19.1	26.2
Pyrite	—	—	—	—	—	—	—	—	—	—	—
Pyroxene	—	—	—	—	—	17.9	—	—	—	3.3	6.1
Quartz	38.1	29.6	34.3	22.5	50.4	38.1	34.8	41.4	43.9	39.0	21.8
Rutile	—	—	—	—	—	—	—	—	—	—	—
Sphene	—	—	—	—	—	—	—	—	—	0.1	—
Zircon	—	—	—	—	—	—	—	—	—	—	—
*Glass	—	—	—	—	—	—	—	—	—	—	—

P Pyroxene included in amphibole data
* Glass is not a mineral but is included in this data

TABLE E.3

PERCENT BASALT COMPOSITION

RINGOLD FORMATION

BASAL RINGOLD UNIT

Well	Depth In Feet	Total	Mesh Size >10	10-40	40-200	<200	
W11-26	427	11.8	ns	ns	<15	10	
W11-26	490	23.8	—	—	—	—	
W19-10	519	—	36.3	—	—	—	>200 = 26.3
E19-1	426	—	100.0	0.0	0.0	0.0	
E19-1	450	21.8	27.2	3.0	<1	<1	
E19-1	488	1.4	1.5	<1	<1	<1	
E19-1	511	37.7	43.8	2.6	<1	<1	

LOWER RINGOLD UNIT

Well	Depth In Feet	Total	>10	10-40	40-200	<200
W19-10	460.5	—	100.0	0.0	0.0	0.0
W19-10	484.5	—	ns	ns	0.0	0.0
E19-1	385	<1	ns	ns	1	<1

MIDDLE RINGOLD UNIT

Well	Depth In Feet	Total	>10	10-40	40-200	<200	
W11-26	203	6.4	6.5	0.0	<1	0.0	
W11-26	293	8.3	5.5	20.8	60.3	0.0	
W11-26	390	9.7	11.4	0.0	5.5	0.0	
W19-10	181	79.9	83.8	91.7	34.1	0.0	
W19-10	234	58.6	—	—	3.3	—	>200 = 54.2
W19-10	275	0.0	ns	0.0	0.0	0.0	
W19-10	285	0.0	ns	0.0	0.0	0.0	
W19-10	365	—	17.2	—	—	—	>200 = 12.8
E27-6	293	13.6	8.9	54.0	5.2	<1	
E27-6	310	51.3	51.3	ns	ns	ns	
E27-6	328	7.2	7.2	ns	ns	ns	

UPPER RINGOLD UNIT

Well	Depth In Feet	Total	>10	10-40	40-200	<200
W11-26	138	3.4	ns	—	—	3.7

TABLE E.3

(CONTINUED)

EARLY "PALOUSE" SOIL

Sample	Depth	Total	>10	10-40	40-200	<200
S[1]		0.0	0.0	0.0	0.0	0.0
T[2]		0.0	0.0	0.0	0.0	0.0
W11-26	110	0.0	0.0	0.0	0.0	0.0

HANFORD FORMATION

Well	Depth In Feet	Total	Mesh Size >10	10-40	40-200	<200	
A[3]		0.0	0.0	0.0	0.0	0.0	
SY[4]	25	23.8	ns	—	—	—	
SY[4]	30	39.1	—	—	—	—	
W10-148	80	—	81.7	18.1	1.5	—	>200 = 16
W11-10	90	—	92.04	—	—	—	10-200 = 173
W14-8	100	—	71.05	—	—	—	10-200 = 11.2
W15-86	56	—	80.5	—	—	—	
W15-86	82	—	66.7	—	—	—	
W15-86	110	—	67.4	—	—	—	
W23-52	100	0.0	0.0	0.0	0.0	0.0	
W23-72	100	13.9	—	—	—	—	
W23-108	105	0.0	0.0	0.0	0.0	0.0	
E13-5	185	—	78.9	—	—	—	10-200 = 2
E13-8	70	—	76.1	—	—	—	10-200 = 9.7
E16-1	60	—	60.82	—	—	—	10-200 = 25.9
E16-1	125	—	99.35	—	—	—	10-200 = 5.2
E24-9	50	—	64.6	—	—	—	
E24-9	90	—	50.8	—	—	—	
E25-2	10	—	96.2	—	—	—	
E25-15	100	0.0	0.0	0.0	0.0	0.0	
E27-6	198	23.5	68.0	21.9	8.2	<1	
E27-6	264	<1	ns	ns	<1	<1	
E28-22	207	10.4	86.3	13.0	2.1	<1	
E33-201	50	—	92.3	—	—	—	>40 = 25.9
E33-244	70	32.7	—	—	—	—	

1 Composite sample from 241-S Tank Farm
2 Composite sample from 241-T Tank Farm
3 Composite sample from 241-A Tank Farm
4 Composite sample from 241-SY Tank Farm excavation

TABLE E.4

SCREEN SIZES AND THEIR RESPECTIVE GRAIN SIZE CLASS

U.S. Standard Sieve Mesh#	Sieve Opening Size: Inches	Sieve Opening Size: Millimeters	Grain Size Nomenclature (Wentworth Grade Scale)
			Very fine pebbles and larger.
10	7.9×10^{-2}	2.00	
			Very coarse to medium sand.
40	1.7×10^{-2}	0.42	
			Medium sand to very fine sand.
200	2.9×10^{-3}	0.074(74μ)	
			Very fine sand to coarse silt
	2.0×10^{-3}	0.050(50μ)	
			Silt
	2.0×10^{-4}	0.005(5μ)	
			Very fine silt to clay
	7.9×10^{-5}	0.002(2μ)	
			Clay

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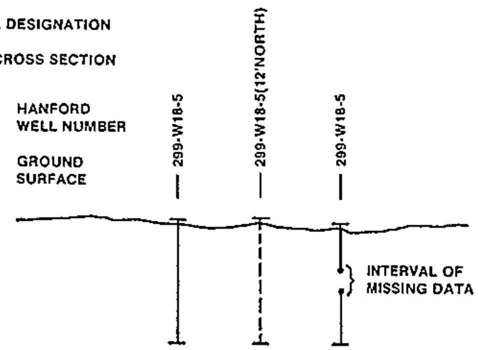
PLATE 1

1. WELL DESIGNATION

CROSS SECTION



SOLID LINE WHEN ON PLANE OF CROSS SECTION
DASHED LINE WHEN PROJECTED TO PLANE OF CROSS SECTION
DISTANCE AND DIRECTION FROM CROSS SECTION ARE GIVEN

MAP VIEW

WELL PLOTTED ON CROSS SECTION	W18-5
WELL NOT PLOTTED ON CROSS SECTION	W18-5
WELL DATA	265

NOTES:
a. ALL 200 AREA WELLS SHOULD BE PREFIXED BY 299-.
b. ALL WELLS PENETRATE WATER TABLE.
C. INFORMATION ON WELL NUMBERING SYSTEM CAN BE FOUND IN DOCUMENT NO BNWL-2296.

2. COORDINATES
BASED ON HANFORD COORDINATE SYSTEM

3. CONTACT LINES
STRATIGRAPHIC
MAJOR FACIES
MINOR FACIES
QUERIED LINE WHERE INFERRED

4. DATUM - MEAN SEA LEVEL

5. CONTOUR LINES IN FEET ABOVE MEAN SEA LEVEL
GOOD CONTROL ———300———
FAIR CONTROL — — — 300 — — —
POOR CONTROL —?——?——?—300—?——?——?—

6. ISOPACH LINES (LINES OF EQUAL THICKNESS) ———20———

7. WATER TABLE

WATER TABLE (6/78)
DATE WATER LEVEL MEASUREMENTS TAKEN

8. HORIZONTAL AND VERTICAL SCALES

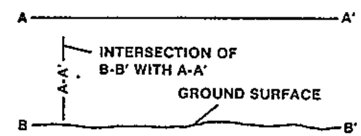
VERTICAL SCALE - AS SHOWN
HORIZONTAL SCALE - AS SHOWN
VERTICAL EXAGGERATION - 10X

9. 200 AREAS PERIMETER FENCE

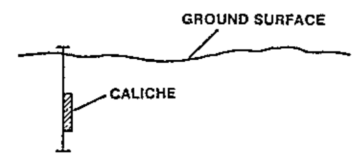
SURFACE MAP
SUB—SURFACE MAP
CROSS SECTION

10. CROSS SECTION LINES
MAP VIEW

CROSS SECTION



11. GEOLOGIC SYMBOLS
CROSS SECTION



MAP VIEW (DRAWINGS H-2-71457 & H-2-71458 ONLY)

HANFORD FORMATION
UPPER RINGOLD
MIDDLE RINGOLD
COLUMBIA RIVER BASALT GROUP

RHO-ST-23

H-2-71451

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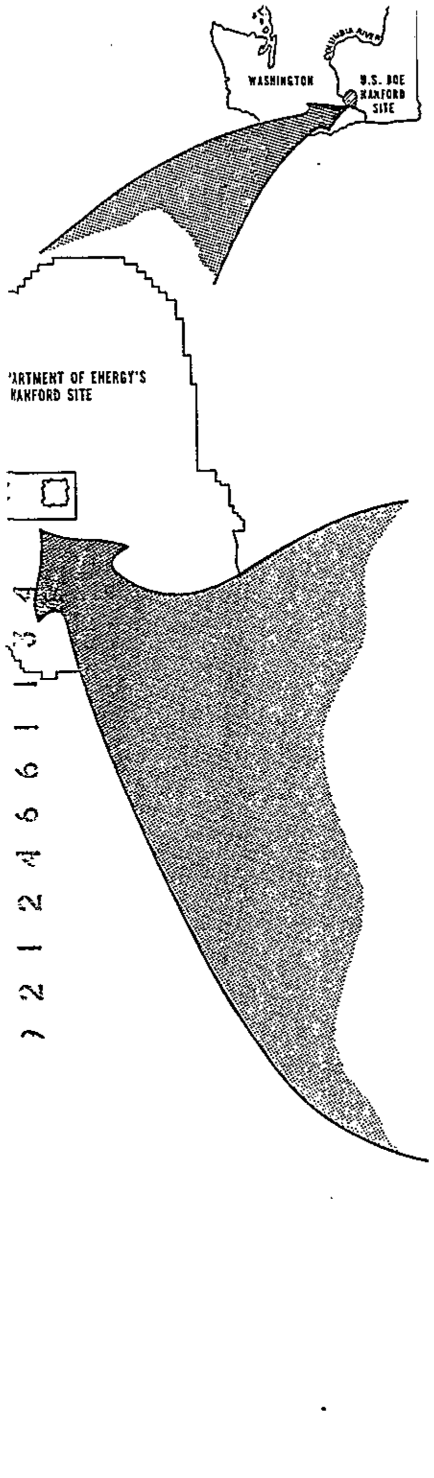
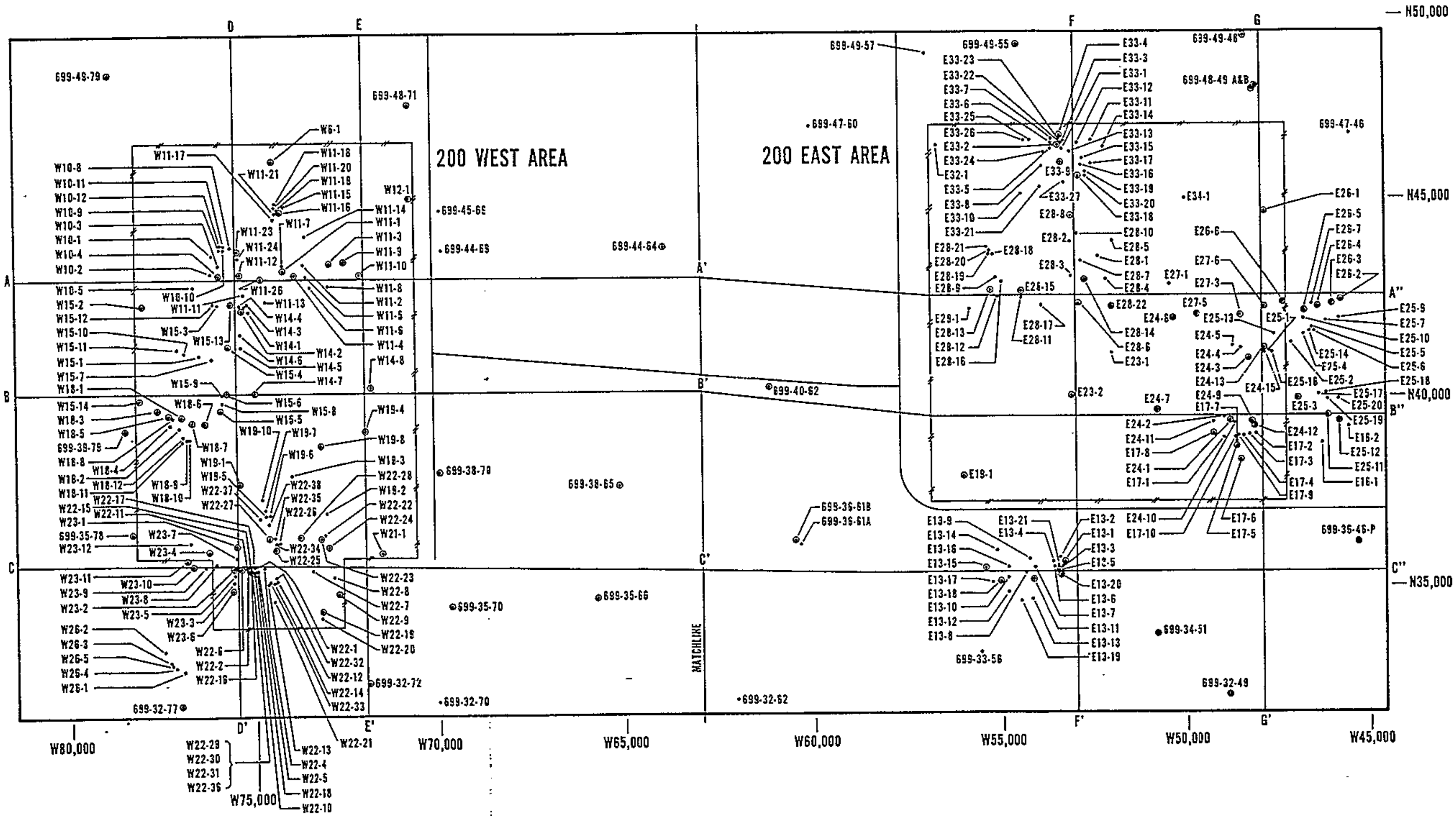
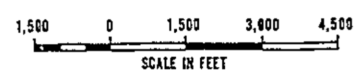
PLATE 2

SEPARATION AREAS
WATER WELL AND CROSS SECTION LOCATION MAP







⊙ WELL PLOTTED ON CROSS SECTION

• WELL NOT PLOTTED ON CROSS SECTION

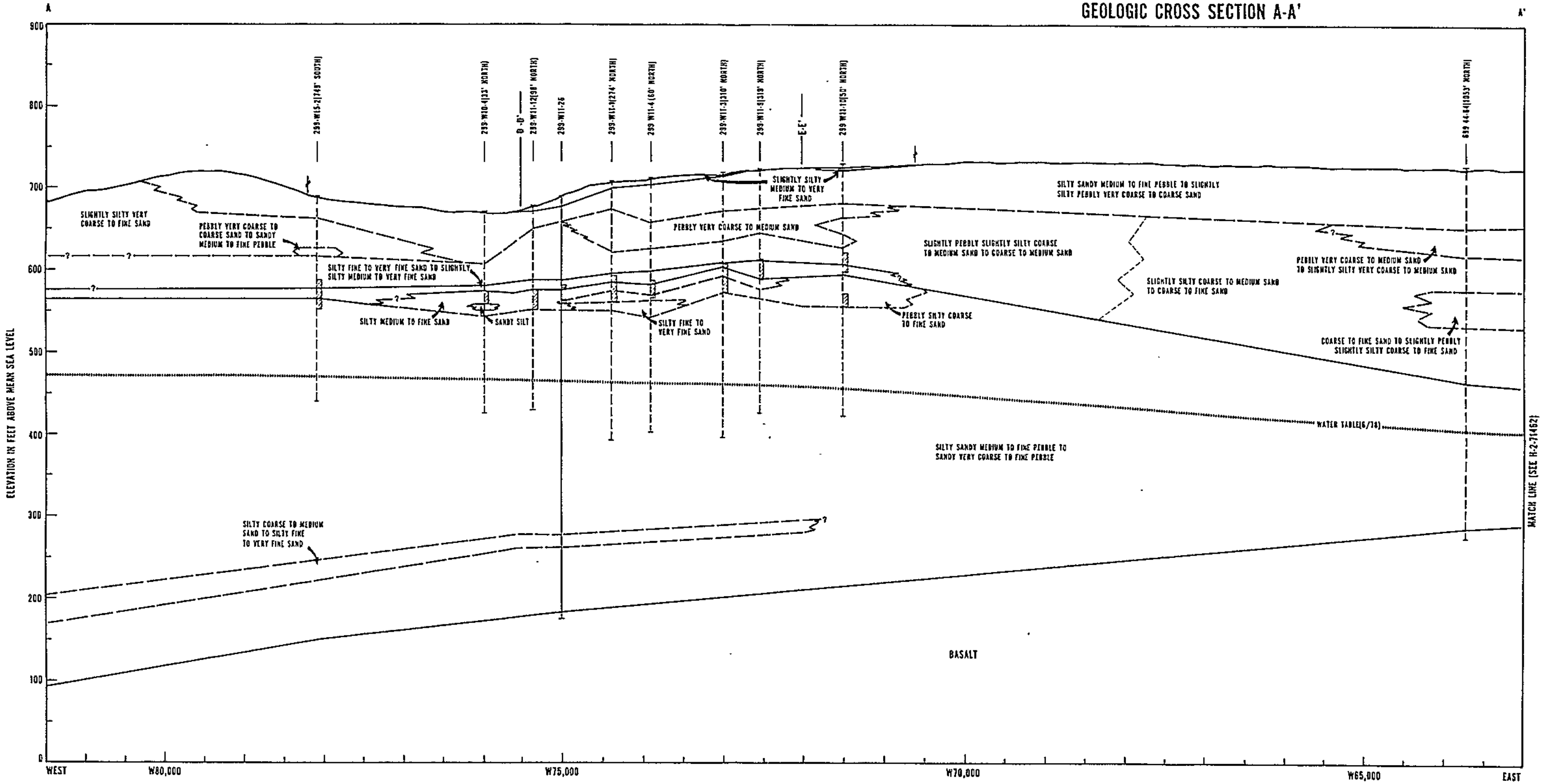
RHO-ST-23

H-2-71460

R7904-6.11

PLATE 3

SEPARATION AREAS
GEOLOGIC CROSS SECTION A-A'



RHO-ST-23

H-2-71461

CROSS SECTION A-A'

500 0 500 1000

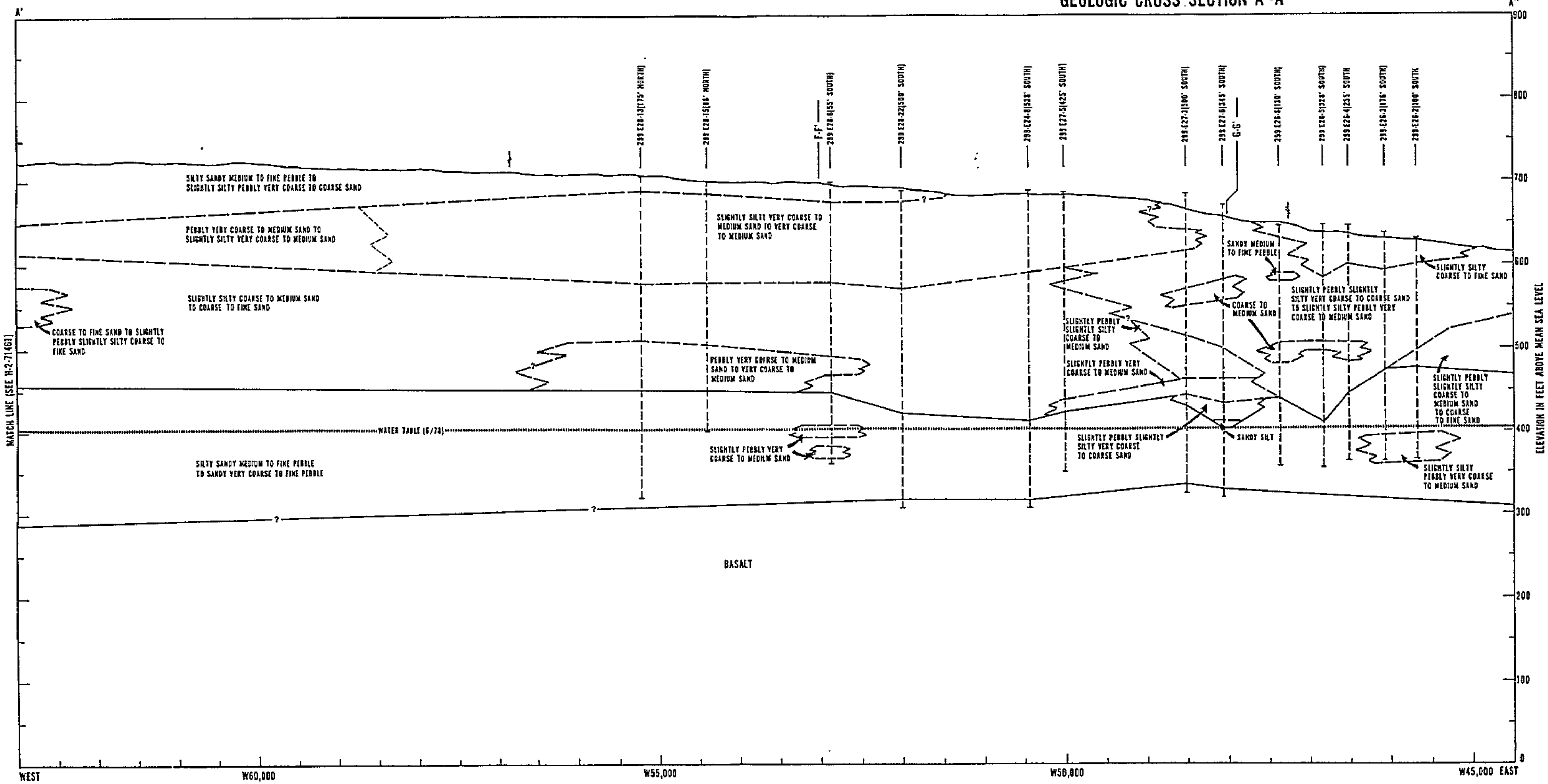
HORIZONTAL SCALE IN FEET

VERTICAL EXAGGERATION 10X

RHO-ST-23

PLATE 4

SEPARATION AREAS
GEOLOGIC CROSS SECTION A'-A''



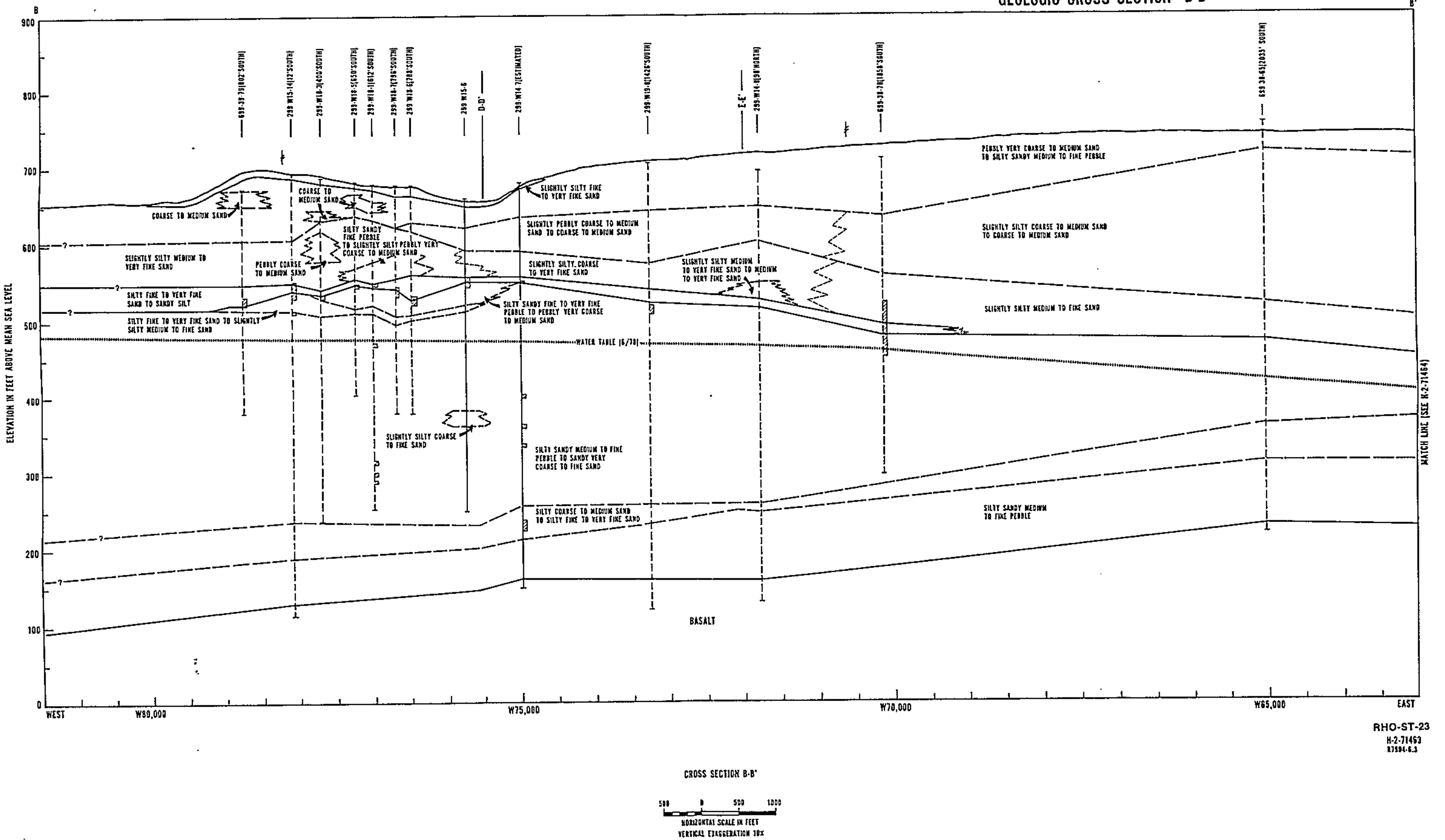
RHO-ST-23
H-2-71462

CROSS SECTION A'-A''

500 0 500 1000
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION 10X

PLATE 5

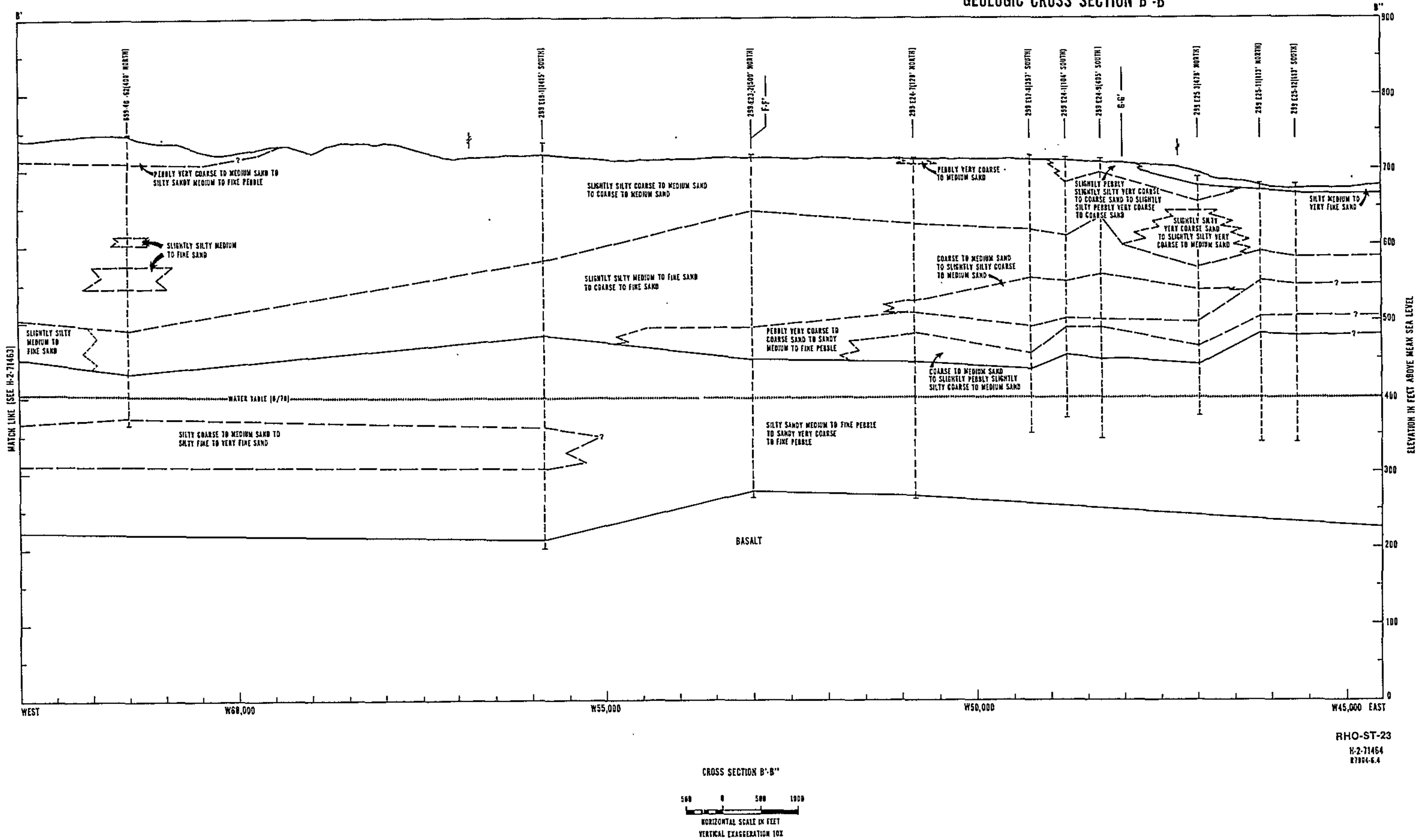
SEPARATION AREAS
GEOLOGIC CROSS SECTION B-B'



RHO-ST-23
H-2-71463

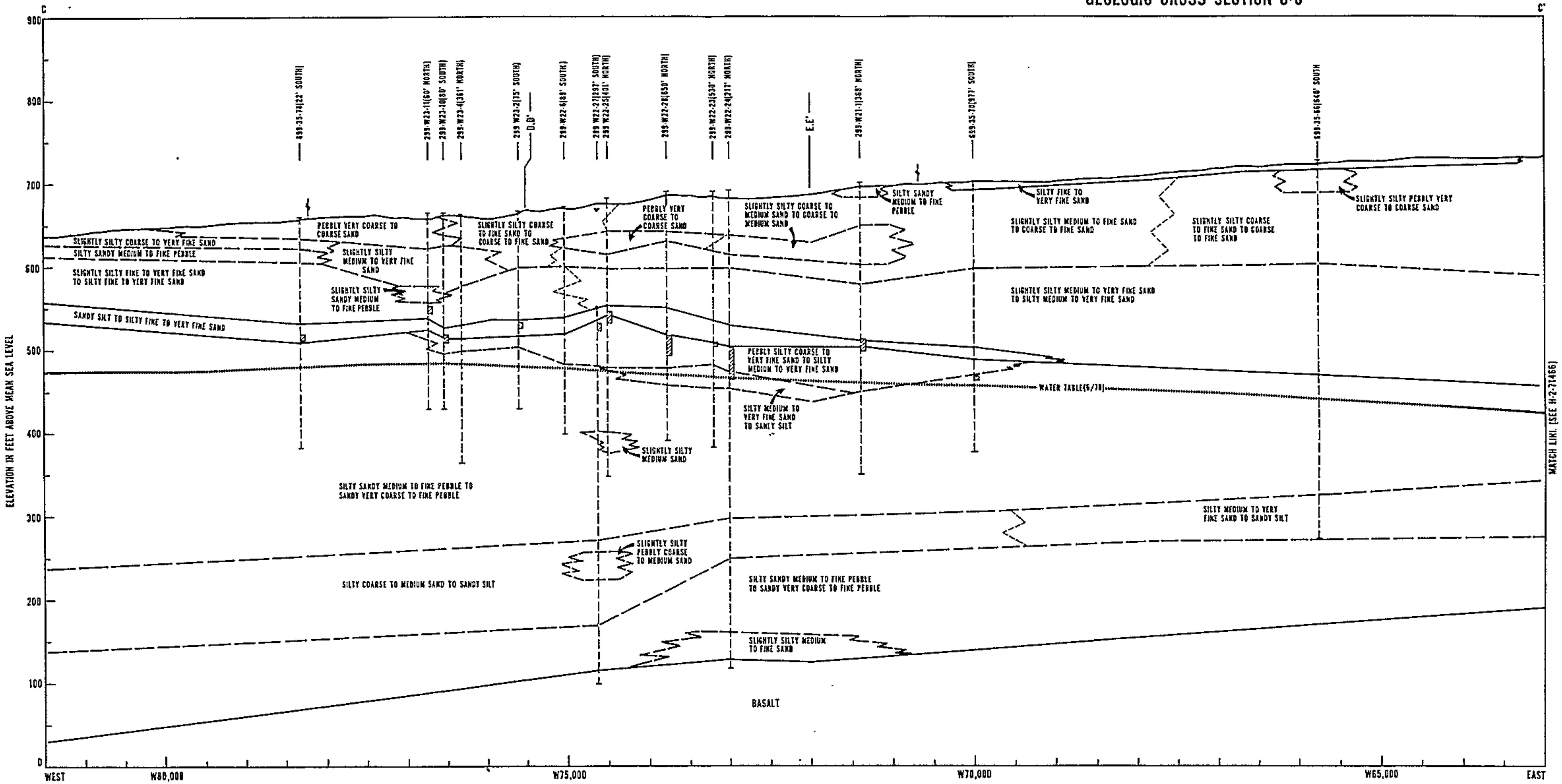
PLATE 6

SEPARATION AREAS
GEOLOGIC CROSS SECTION B'-B''



RHO-ST-23

PLATE 7
SEPARATION AREAS
GEOLOGIC CROSS SECTION C-C'



CROSS SECTION C-C'

500 0 500 1000

HORIZONTAL SCALE IN FEET

VERTICAL EXAGGERATION 10X

RHO-ST-23

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R7884-6.5

PLATE 8

SEPARATION AREAS
GEOLOGIC CROSS SECTION C'-C''

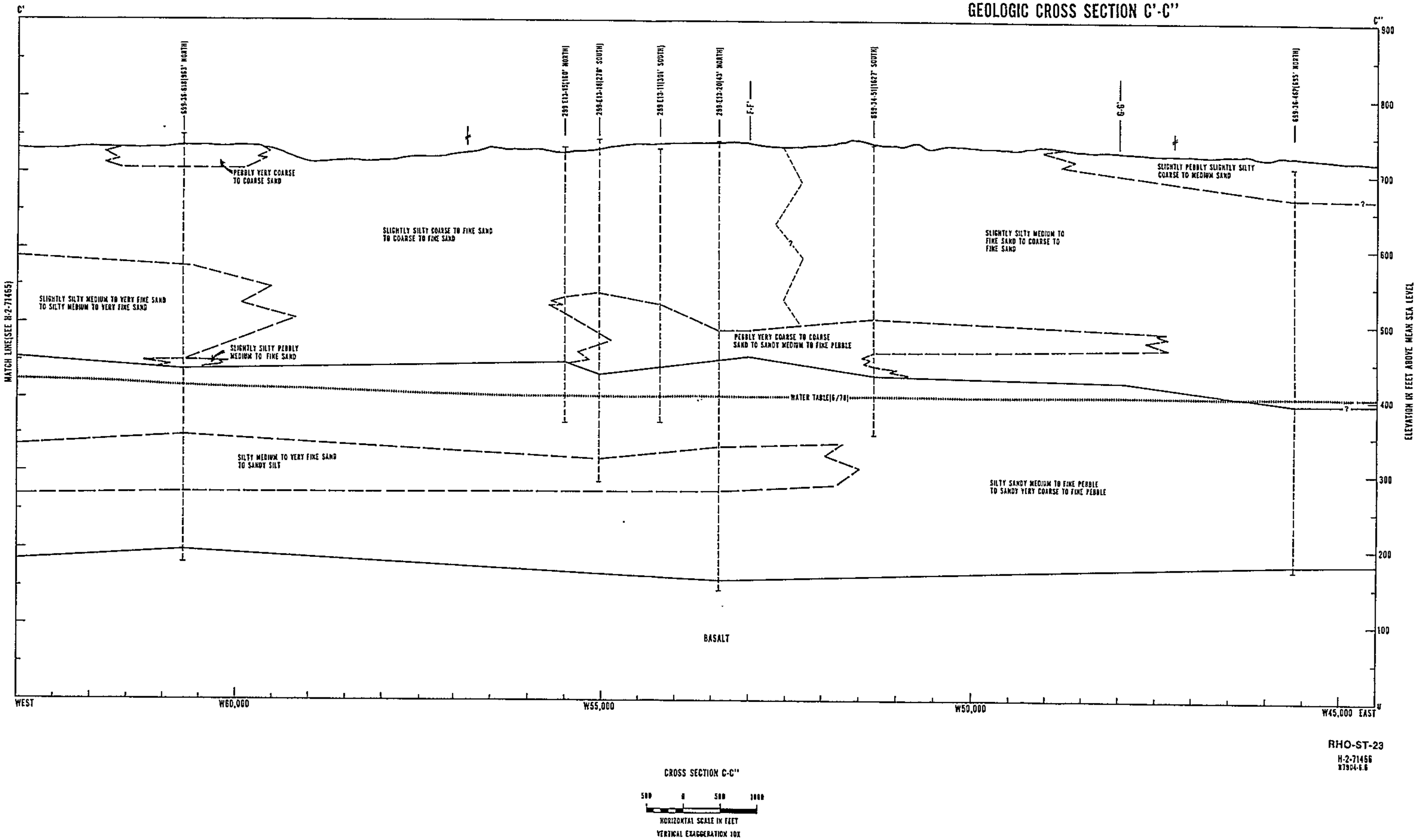
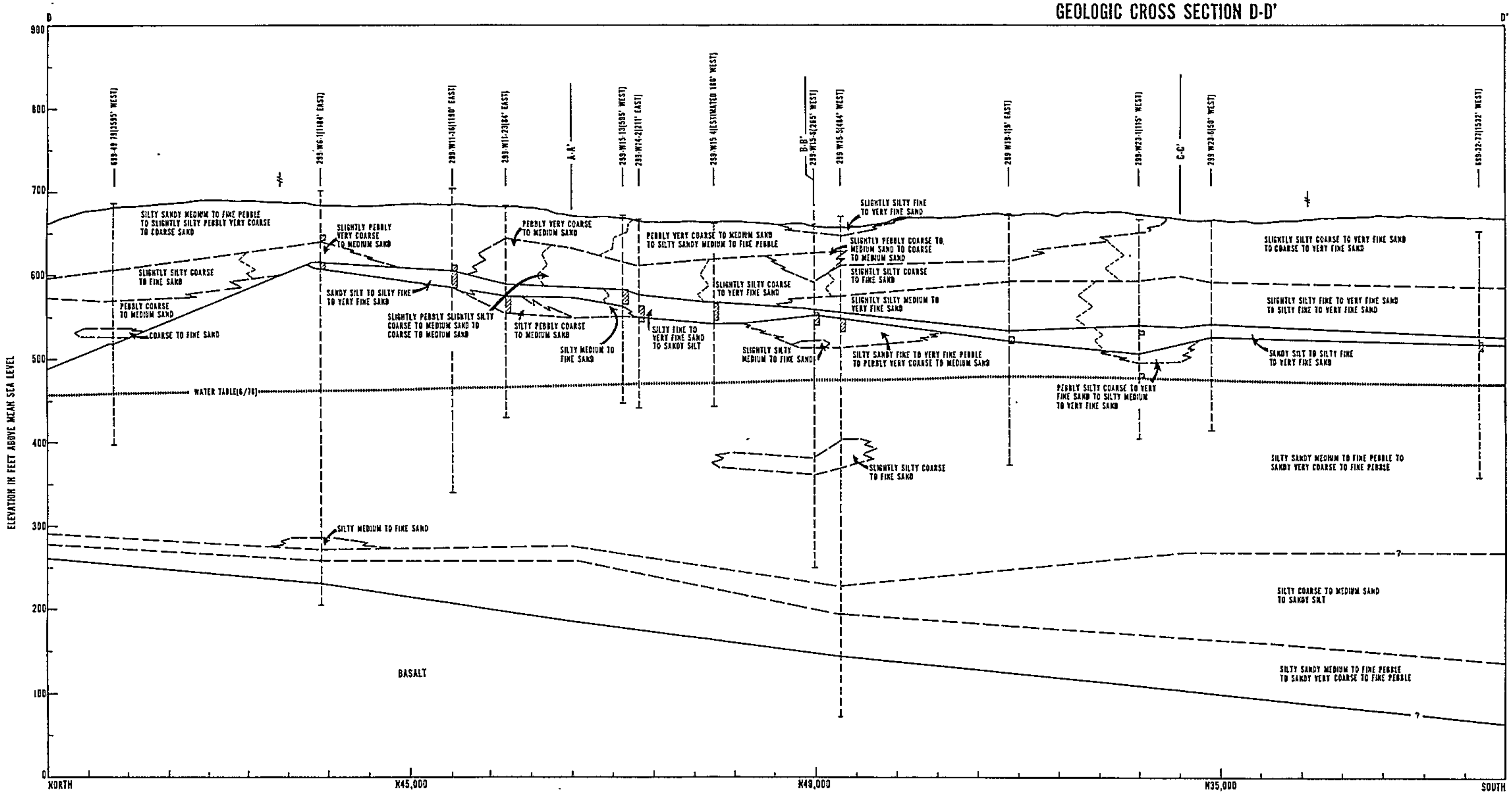


PLATE 9

SEPARATION AREAS
GEOLOGIC CROSS SECTION D-D'



RHO-ST-23
R-2-71467

CROSS SECTION D-D'

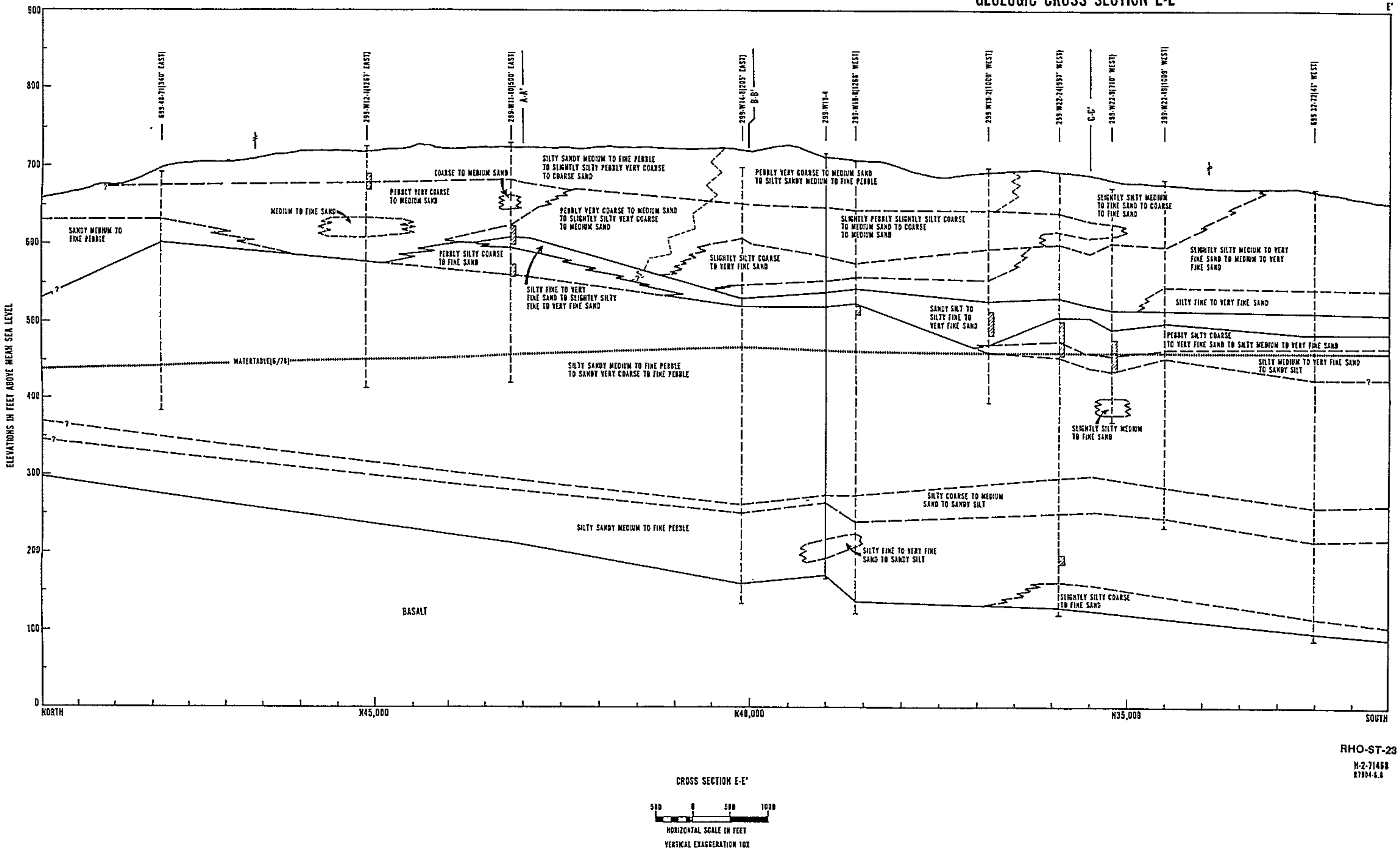
500 0 500 1000

HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION 10X

9 2 1 2 4 5 6 1 1 4 1

PLATE 10

SEPARATION AREAS
GEOLOGIC CROSS SECTION E-E'



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H-2-71468

PLATE 11

SEPARATION AREAS
GEOLOGIC CROSS SECTION F-F'

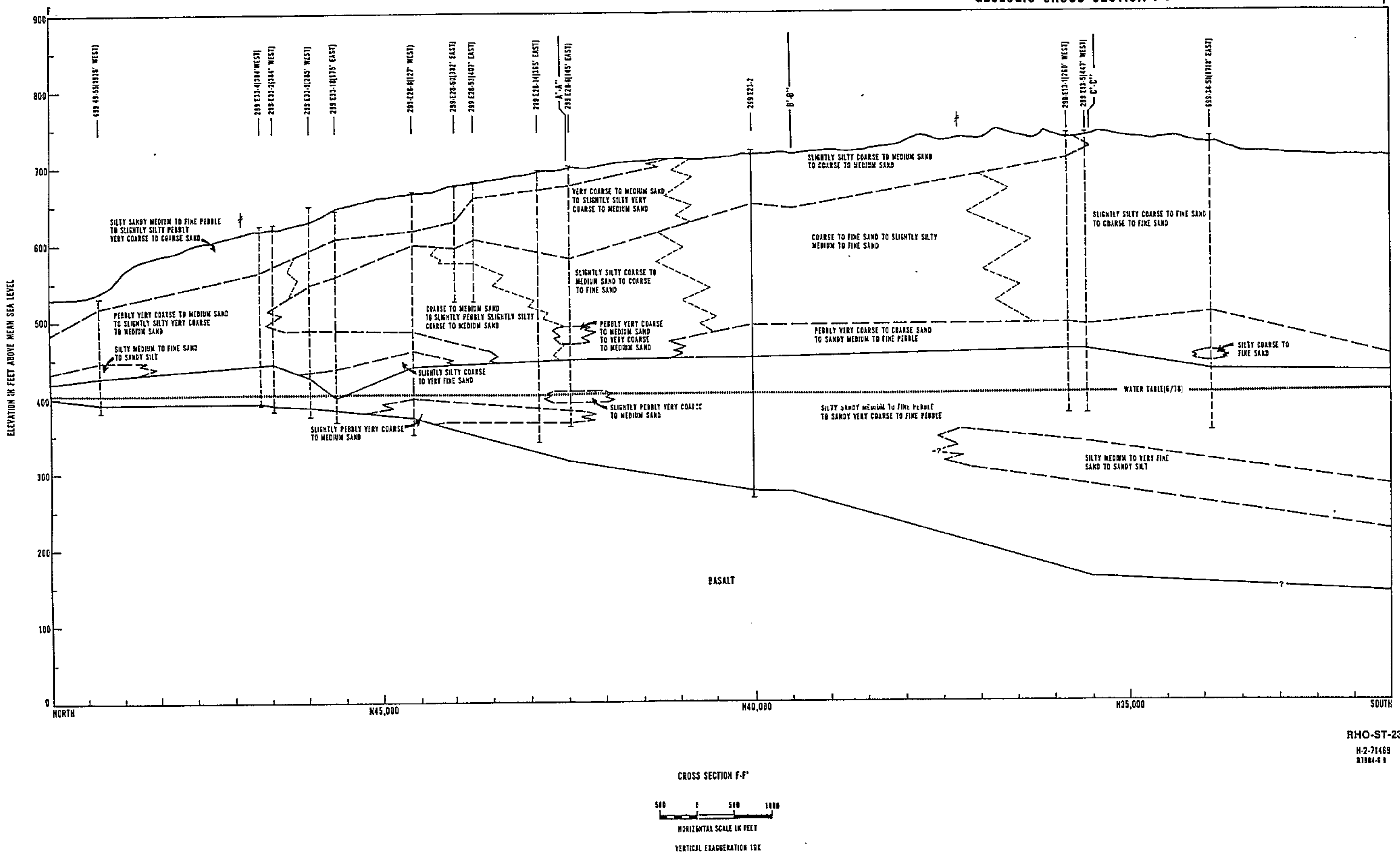

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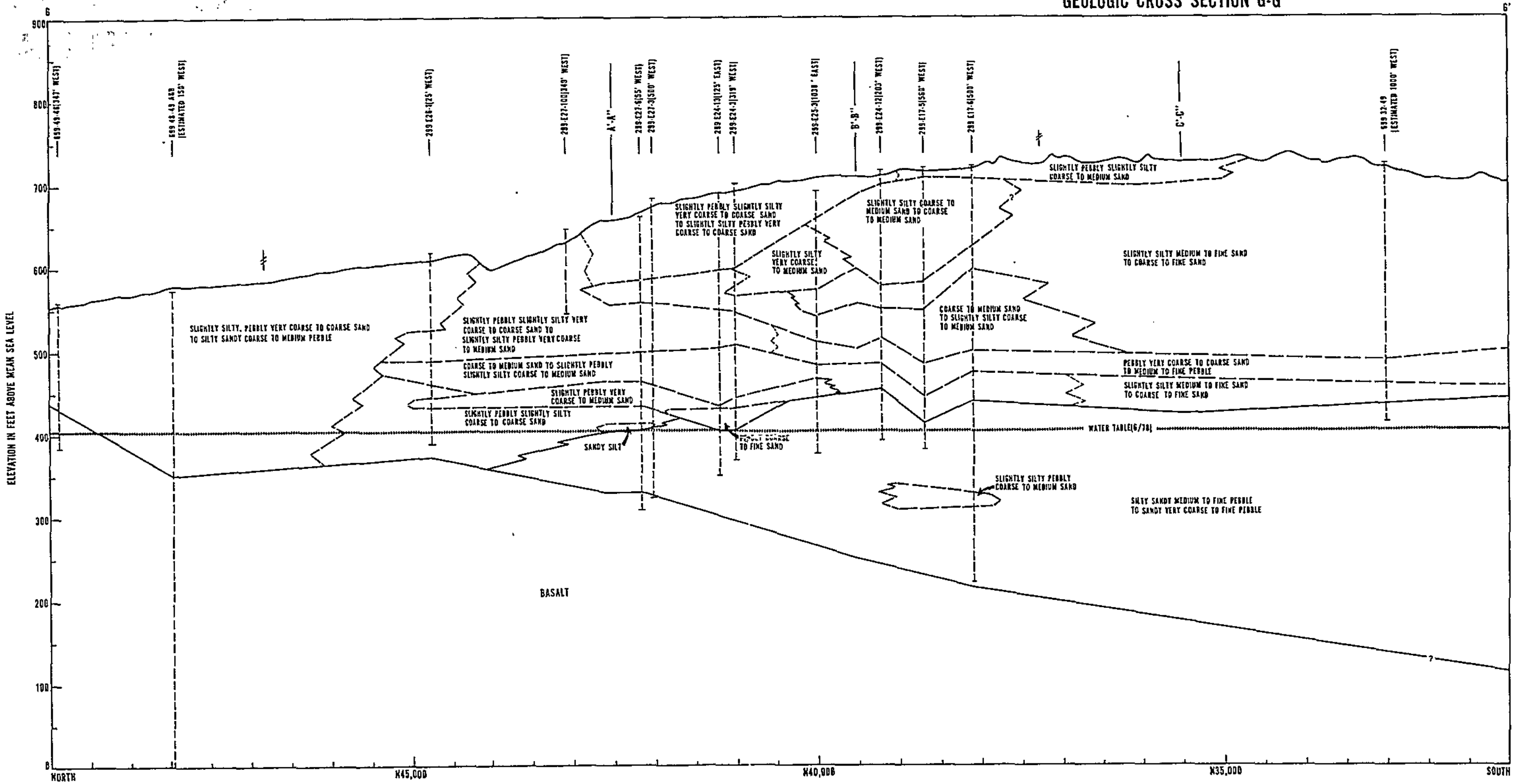
PLATE 12

SEPARATION AREAS
GEOLOGIC CROSS SECTION G-G'



CROSS SECTION G-G'

VERTICAL EXAGGERATION 10X

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